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DEVELOPMENT AND EVALUATION OF REPAIRS FOR EMP LEAKS IN CONDUIT SYSTEMS

D. J. Leverenz, et al

Army Construction Engineering Research Laboratory
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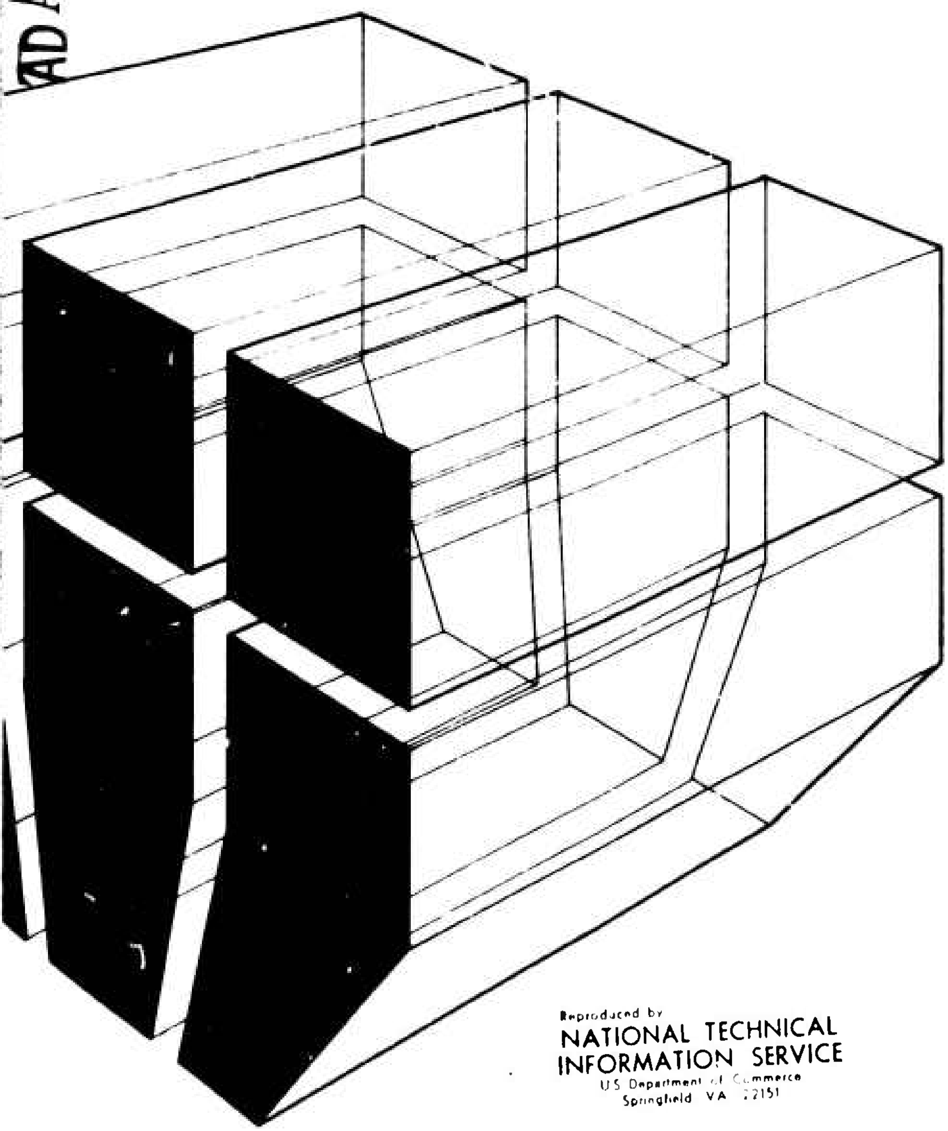

by
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This report discusses the development and evaluation of repairs for EMP leaks in conduit systems at the SAFEGUARD site. Repairs for 4-in. explosion-proof conduit unions, communications cable-gripper boxes, and non-RFI tight flexible conduit are studied.

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FOREWORD

This investigation was conducted for the U. S. Army Engineer Division, Huntsville (HND), under IAO 72-20, dated 2 August 1972, including subsequent change orders. This work was performed by the Facilities Engineering and Construction Division (FE) of the U. S. Army Construction Engineering Research Laboratory (CERL).

Appreciation is expressed to Dr. J. Verdeyen and M. J. Pollock for their guidance, and to J. Simon, L. Greep, M. Hill, W. Croissant, D. Seiber, E. Spier, and T. Tuttle, all of CERL, for their assistance in the conduct of this investigation. Appreciation is also expressed to F. Smith and M. Carter of HND for their suggestions during this program.

COL M. D. Remus is the Commander and Director of CERL and Dr. L. R. Shaffer is the Deputy Director. Mr. E. A. Lotz is Chief of FE.

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DEVELOPMENT AND EVALUATION OF REPAIRS FOR EMP LEAKS IN CONDUIT SYSTEMS

1 INTRODUCTION

Extensive use has been made of rigid-wall, galvanized steel conduit for providing EMP shielding for power and signal cables at the SAFEGUARD site. These cables interconnect the various shielded volumes that house the critical electronic equipment used at the site. The conduits can connect shielded volumes in one building, or they can interconnect different buildings, in which case they are usually buried. CERL has made an extensive study of the shielding properties of these conduits and the hardware used in constructing the conduit runs.[1]

There are many cases where the shielding can be degraded due to faulty construction or improper design. Generally, these conditions are noted by the inspectors and repaired before the cables have been pulled. On some occasions, however, the faulty condition is not discovered until after the cables have been pulled. In this case, it is often impossible or impractical to replace the faulty device and some method of repair must be devised that does not require disassembly of the conduit run.

The faulty condition might be found before the cables have been pulled, but the point of the fault would be virtually inaccessible for disassembly; and, thus, an external fix would be required. In some of these cases the faulty condition can be cut out, but there would be no conduit threads to which a replacement could be affixed. Consequently, an external fix would still be required.

To date, three conditions have been identified at the SAFEGUARD site that require a special fix: inadequate cable-gripper box covers, leaky Sealtite flexible conduits, and broken 4-in. explosion-proof unions. It is the responsibility of the Huntsville Engineering Division to correct these conditions. This report details the problems that led to the existence of the above conditions and describes the necessary corrective measures developed by CERL.

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[1] D. J. Leverenz, R. G. McCormack, and P. H. Nielsen, *The Effect of Conduit Coupling Conditions on the EMP Shielding of Conduit Joints*, Letter Report E-4 (Construction Engineering Research Laboratory [CERL], July 1972); Leverenz, McCormack, and Nielsen, *EMP Evaluations of Conduit Unions, Flexible Conduits, Unilets, and Heated Conduit Couplings*, Letter Report E-11 (CERL, September 1972); Leverenz, McCormack, and Nielsen, *EMP Evaluations of Conduit System Related Items*, Letter Report E-44 (CERL, April 1973).

Although the development of these fixes presented three separate problems, there was a distinct similarity between them, especially in the theoretical basis leading to their development. It was therefore decided to include the development of the three fixes in one report where the similarities could be noted, and from which some general guidelines for the development of future fixes could be made.

2 DEVELOPMENT AND EMP EVALUATION OF REPAIRS FOR 4-IN. EXPLOSION-PROOF CONDUIT UNIONS

Background. Many of the conduit runs at the SAFEGUARD site are too long to be assembled in one piece. When this condition exists, the system design specifies that explosion-proof unions (UNF or UNY) be used at periodic intervals to simplify assembly of the conduit runs, and to pull the assembled conduit runs together. These unions have been previously tested for EMP leakage and were found to be acceptable when properly installed. After assembly of the runs, the conduits are buried and cables pulled through them to complete the conduit installation.

After several conduit runs had been buried (many with the cables pulled through them), it was observed that water was leaking into some of the conduits. Subsequent investigation showed that the water leakage occurred as a result of improper installation of or fracturing of the explosion-proof unions. Improper installation was generally the result of the unions being used at a point where mating runs met at an angle or where conduit ends were separated by an excessive distance. In either case, it was not possible to sufficiently tighten the union to force the conduit ends to align properly and hence draw the union mating surfaces completely together. Obviously, conditions at the union that would allow leakage of gases or liquids into the conduit might allow leakage of EMP energy. To assess the condition of the conduit runs at SAFEGUARD, a series of tests were performed wherein each conduit run was evaluated for air leakage. Testing was then performed at CERL to determine whether air leak rates and EMP leakage for explosion-proof conduit unions could be correlated. Test results indicated that a correlation does exist[2] and that some of the conduit runs were unacceptable. The unacceptable runs were to be dug up and repaired.

It was CERL's task to determine the method for repairing the improperly installed conduit unions. The repair method had to meet the following conditions:

a. Where possible, repairs are to be made by carefully tightening the union for proper mating of all surfaces.

[2] R. F. Glaser, *EMP/Air-Flow Correlation Tests--Clean Appleton Unions*, Memorandum for File (Bell Laboratories, April 1973).

b. If it is not possible to tighten the union properly, then an external fix should be applied to the exterior of the conduit and union.

c. If neither a nor b is satisfactory, then the fix can be accomplished by sawing or otherwise removing the union from the conduit run and using some form of split coupling in conjunction with various gasket material.

d. An acceptable repair is one that provides electrical characteristics equivalent to a wrench-tightened new and clean union. Such unions had been found in previous studies[3] to have sense-wire currents as high as 20 mA and as low as 0.9 mA with a 150-amp peak current pulse injected into the test sample.* Ten milliamperes or less was the value chosen as a goal for this study.

e. Evaluation of the various repair techniques was to be made by the injected current pulse technique.[4]

Experimental Procedure. The techniques used for all tests described herein involved injection of a current pulse into the conduit sample under test and measurement of the short-circuit current on a sense wire inside the conduit. The injected current pulse had a shape approaching a double exponential with a rise time (0 to 90 percent) of less than 10 nanoseconds and a fall time (e-fold) of 4 microseconds. The setup, facilities, equipment, instrumentation, and procedure used in performing the tests described herein are the same as those used in the conduit coupling tests.[5]

The test current pulse was injected into a parallel conduit transmission line, the ground side of which contained the test sample. A 12-in.-long, 4-in. I.D. conduit stub was welded to a shielded enclosure with a standard taper-threaded 4-in. coupling threaded and welded onto

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[3] D. J. Leverenz, R. G. McCormack, and P. H. Nielsen, *Development and EMP Evaluation of Repairs for 4-In. Explosion-Proof Conduit Unions*, Letter Report E-45 (CERL, July 1973); Leverenz, McCormack, and Nielsen, *EMP Evaluations of Conduit Unions, Flexible Conduit Unilets, and Heated Conduit Couplings*, Letter Report E-11 (CERL, September 1972); Leverenz, McCormack, and Nielsen, *EMP Evaluations of Conduit System Related Items*, Letter Report E-44 (CERL, April 1973).

[4] Leverenz, McCormack, and Nielsen, *The Effect of Conduit Coupling Conditions on the EMP Shielding of Conduit Joints*, Letter Report E-4 (CERL, July 1972).

[5] Leverenz, McCormack, and Nielsen, *The Effect of Conduit Coupling Conditions on the EMP Shielding of Conduit Joints*, Letter Report E-4 (CERL, July 1972).

* Bell Telephone tests at CERL, February - April 1973.

the stub. One end of the test sample conduit was connected to this stub, and the other end had an end cap screwed onto it.

The sense wire inside the test sample was connected to the center of the end cap and extended through the test sample and mounting stub to the inside of the shielded enclosure. The sense wire was unsupported and was allowed to assume its own rest position inside the conduit. Tests on conduits with uniform defects or with a leakage source around the circumference, i.e. union or rusty coupling, indicated that wire position or tension has no significant effect on sense-wire current. For shortcircuit current (I_{sc}) measurements, the sense-wire end inside the shielded enclosure was grounded to the conduit stub. The sense wire thus formed a short co-axial transmission line with the conduit test sample.

For all I_{sc} measurements described herein, a Tektronix P-6021 current-probe type 134 amplifier and a type 454, 7623, or 7904 oscilloscope were used. This setup had a low-frequency response to 10 Hz and provided a nondistorted record of the diffusion and leakage current. Figure 1 shows a schematic of the test setup.

Preparation of Test Samples

Sealing Compounds. Initially, an effort was made to locate a conductive sealing compound that would provide sufficient EMP shielding, be quick and easy to apply, and possibly provide a water seal for the leaky union. This resulted in the selection of the following compounds: *E-POX-E Steel Filler, Liquid Solder,* and *Liquid Filler for Steel Repairs*--all distributed by Duro Plastics, Cleveland, OH; and *EMBECO #153 Metallic Aggregate Grout*--distributed by Master Builders, Cleveland, OH. Each of these compounds was applied to a flat surface and allowed to cure. After curing, the resistance of each was measured with a volt-ohm meter (VOM).

In addition, Tecknit CON/RTV-1* conductive silicone rubber was applied in beads to a hand-tight UNF union that had been thoroughly cleaned and wire-brushed (Figure 2). After the compound had been allowed to cure, the treated union was subjected to the injected current pulse test, and the resulting data were compared to data obtained from similar tests performed on an untreated union.

Shrouds. Various materials were used as a wrap or shroud over a hand-tight UNF union to determine if this technique would provide a

* One part RTV silicone/silver conductive adhesive sealant, volume resistivity 1 x 10^{-2} ohm - cm @77°F, 50 percent RH, marketed by Technical Wire Products, Inc., Cranford, NJ.

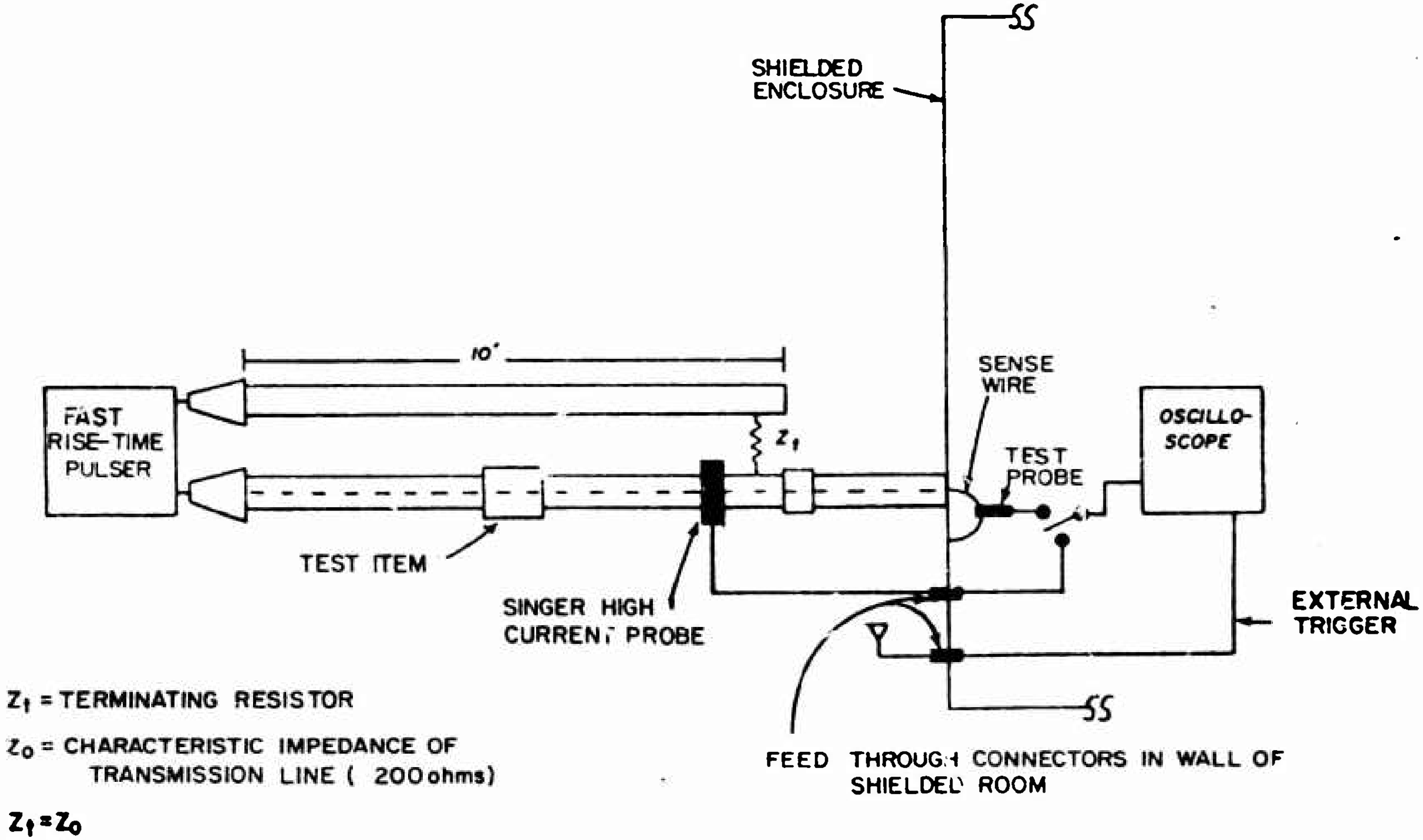

Figure 1. Block diagram of parallel conduit transmission-line test setup.

Figure 2. UNF union with CON/RTV-1 conductive sealant beads.

successful fix. In all cases, the union and the conduit surface near the union were well cleaned and wire-brushed prior to application of the shroud. Each shrouded union was then subjected to the injected current pulse test.

The first type of shroud tested consisted of eight wire-per-inch (i.e., 1/8-in. wire spacing) galvanized steel hardware cloth (wire diameter approximately 0.018 in.), wrapped both one layer thick and three layers thick around the union. The hardware cloth was held in place with metal shipping bands* that were installed as tightly as possible with a banding machine.** As shown in Figure 3, an automotive screw type hose clamp† was also placed to hold the shroud in place. A variation of this approach, which was intended to reduce the contact resistance between the conduit and the screen, involved the use of a Skinner emergency pipe clamp†† on each end of the wrapped shroud (tightened to approximately 80 ft-lb), as shown in Figure 4. A modification of the above shroud, consisting of one layer of eight wire-per-

* Signode-steel banding stock, 0.015 x 1/2 in. distributed by Signode Corp., Chicago, IL.

** Signode Tensioner, model: P 3/8, size: 3/4, distributed by Signode Corp.

† "Sure-Tite" stainless steel, screw type hose clamp, distributed by Whittek Manufacturing Co., Chicago, IL.

†† Skinner-Seal emergency pipe clamp for 4-in. standard steel pipe, manufactured by M. B. Skinner Co., South Bend, IN.

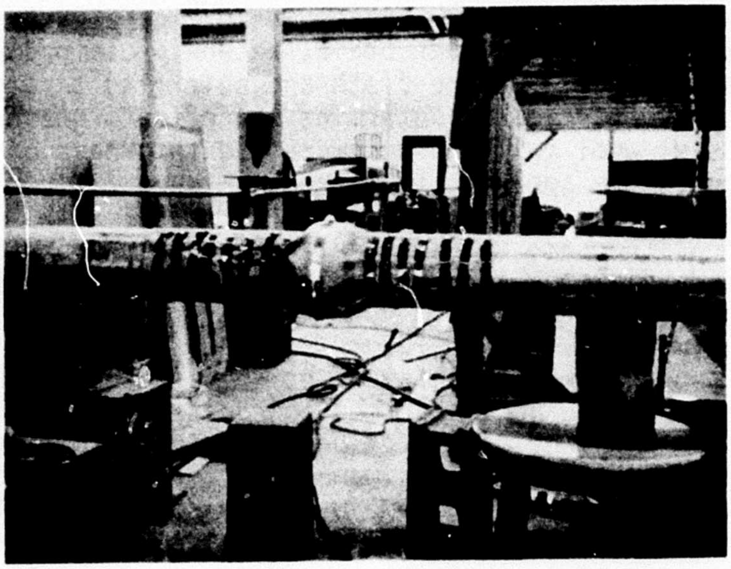

Figure 3. UNF union wrapped with hardware cloth.

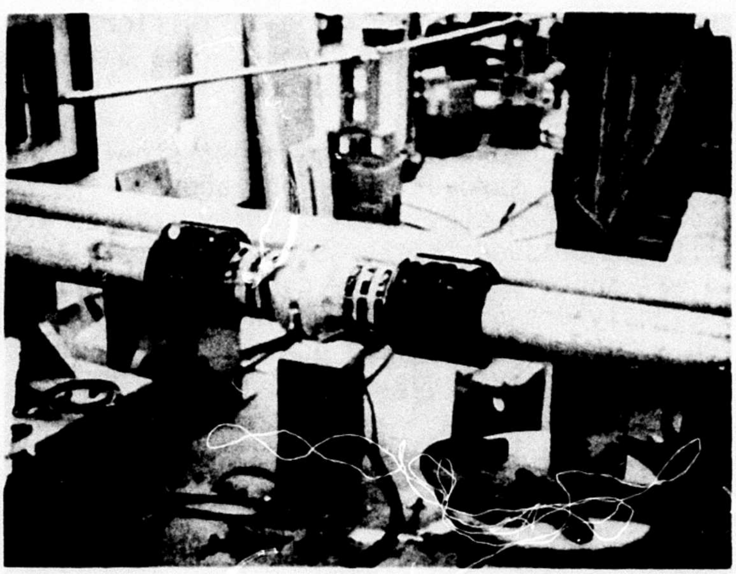

Figure 4. UNF union wrapped with hardware cloth and clamped with Skinner pipe clamps.

inch hardware cloth, wrapped with three additional layers of shielding tape,* was also tested (Figure 5). As shown in Figure 6, tests were also conducted with a tinned copper braid, securely clamped with screw type hose clamps over the hardware cloth and shielding tape shroud. An additional test was performed to determine the effectiveness of wrapping the union with steel wool (with an uncompressed thickness of approximately 1 1/2 in.) before applying the shroud (Figure 7).

Figure 8 shows the same type of test sample using 20 wire-per-inch copper screen (wire diameter approximately 0.014 in.) securely held by steel shipping bands.

The second type of shroud that was tested was made of sheet steel formed to fit around the union. Various thicknesses of steel, in combination with an assortment of clamps or bands designed to tightly secure the shroud to the conduit with a minimum of contact resistance, were tested. One nonsteel shroud of this type was also tested. This shroud was formed from a special highly permeable metal, Conetics foil,** secured in place with steel shipping bands (Figure 9).

Several variations were tried with a hand-formed shroud made of 26-gauge galvanized sheet metal.† Tests were performed with this shroud securely held in place with steel shipping bands (Figure 10), and with and without steel wool wrapped between the shroud and the conduit union. Additional methods of securing this shroud were tested. These included using, on each end of the shroud, one 5-in. automotive style (U-bolt type) muffler clamp (Figure 11), two 5-in. muffler clamps, and one Skinner emergency pipe clamp (Figure 12). The muffler clamps above were tightened to approximately 30 ft-lb of torque. The Skinner clamp was tightened to approximately 80 ft-lb of torque.

Tests were also conducted on 28-gauge sheet steel shrouds with construction similar to the shrouds described above. Two configurations were tried, each of which had steel wool tightly wrapped around the union and conduit (uncompressed thickness approximately 1 1/2 in.) before the shroud was installed. In one configuration, the shroud was held in place by tightly drawn, steel shipping bands, while the other configuration used a Skinner pipe clamp on each end of the shroud, in addition to the steel shipping bands.

A third shroud of this type was professionally fabricated by welding

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* Tecknit EMC Shielding Tape; tin-coated, copper-clad, steel-knitted mesh, Part No. 23-50225, distributed by Technical Wire Products Co.

** Conetics foil, 0.006 in. thick, relative permeability of 225,000, 78 percent nickel, 1 1/2 percent chrome, 4 1/2 percent copper, 16 percent iron, dry H annealed, volume resistivity of 60 x 10^{-6} ohms-cm, manufactured by Perfection Mica Co., Bensenville, IL.

† Galvanized on both sides--of the type commonly used in the construction industry (for ductwork, etc.).

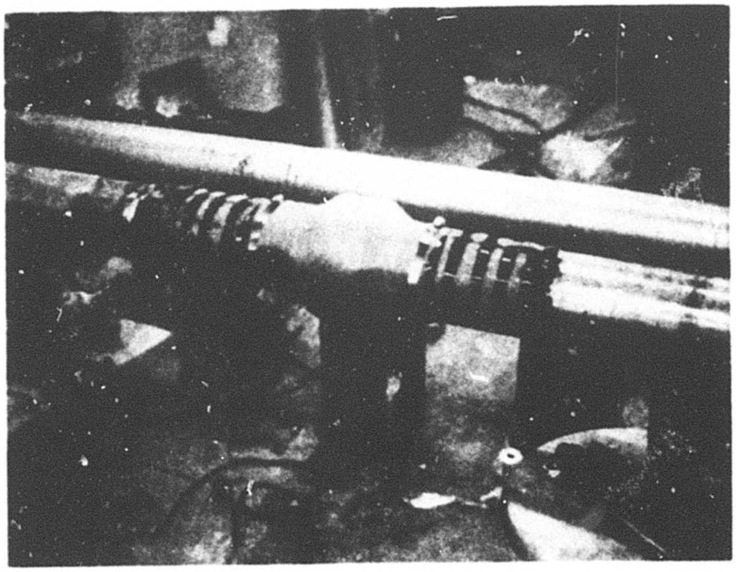

Figure 5. UNF union wrapped with hardware cloth and shielding tape.

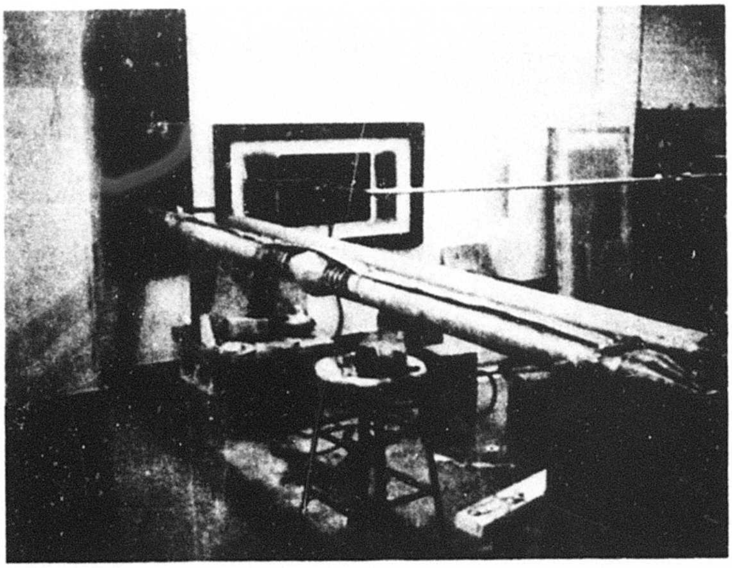

Figure 6. UNF union wrapped with hardware cloth and shielding tape, plus tinned copper braid.

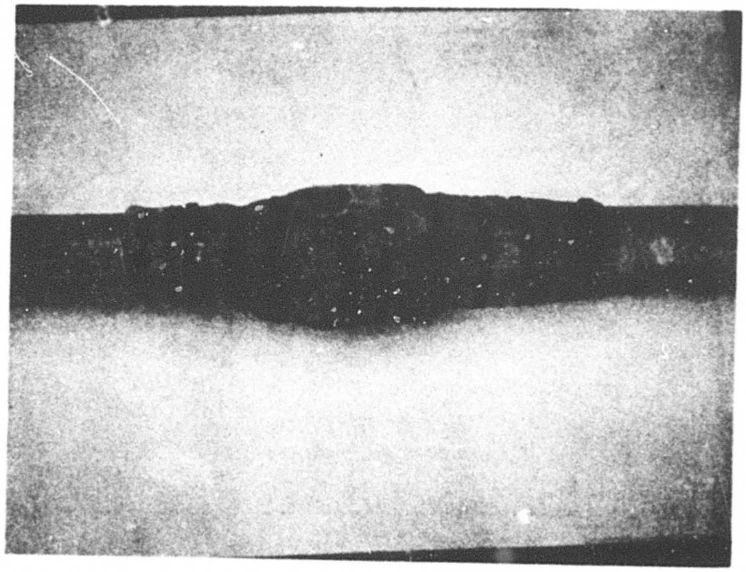

Figure 7. UNF union wrapped with steel wool and one layer of hardware cloth.

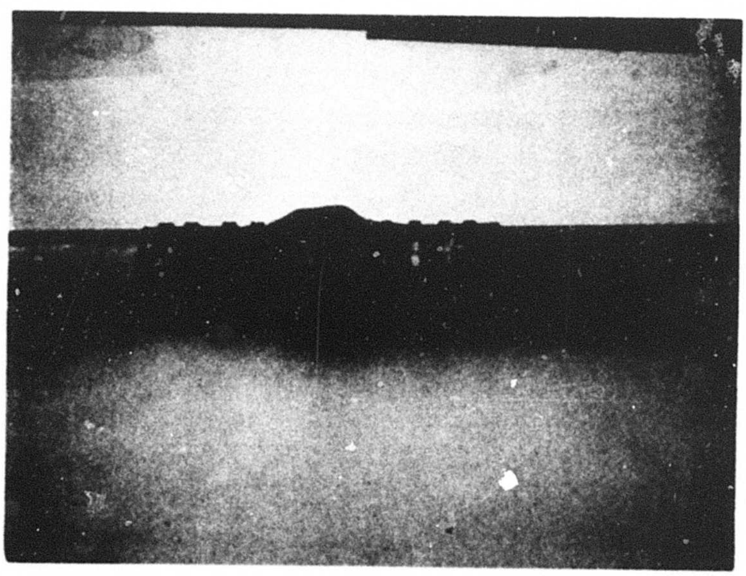

Figure 8. UNF union wrapped with one layer of copper screen.

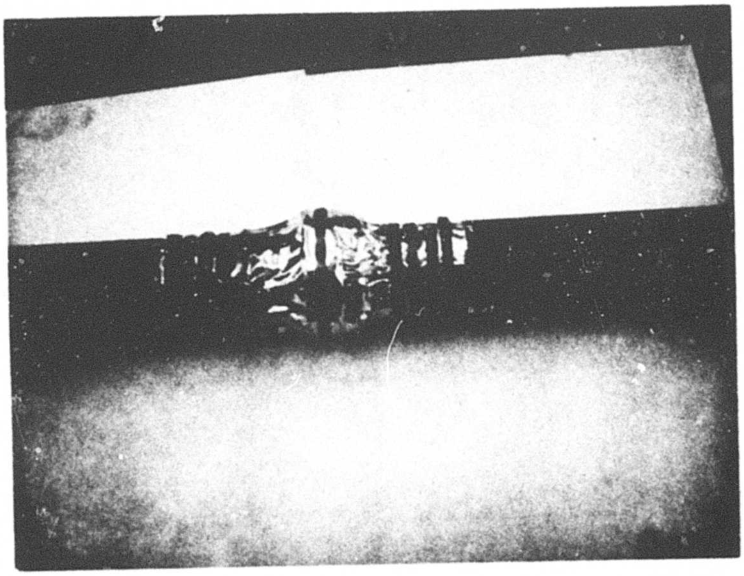

Figure 9. UNF union with Conetics foil shroud.

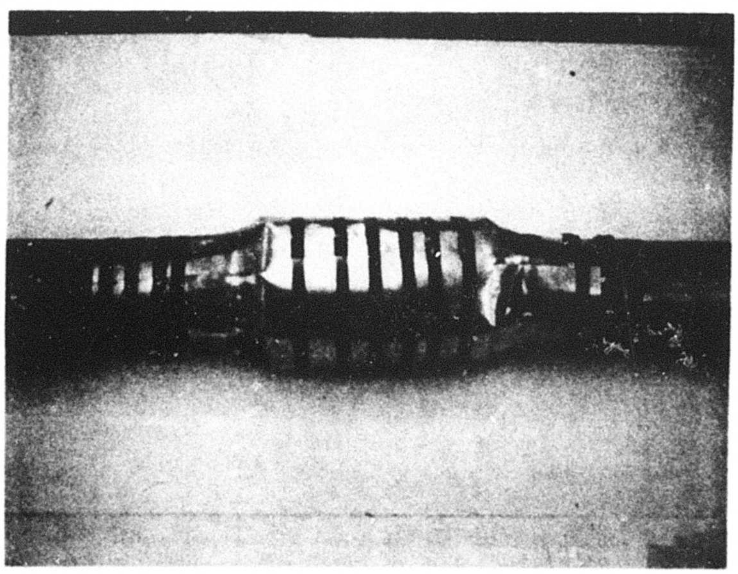

Figure 10. UNF union with 26-gauge sheet steel shroud.

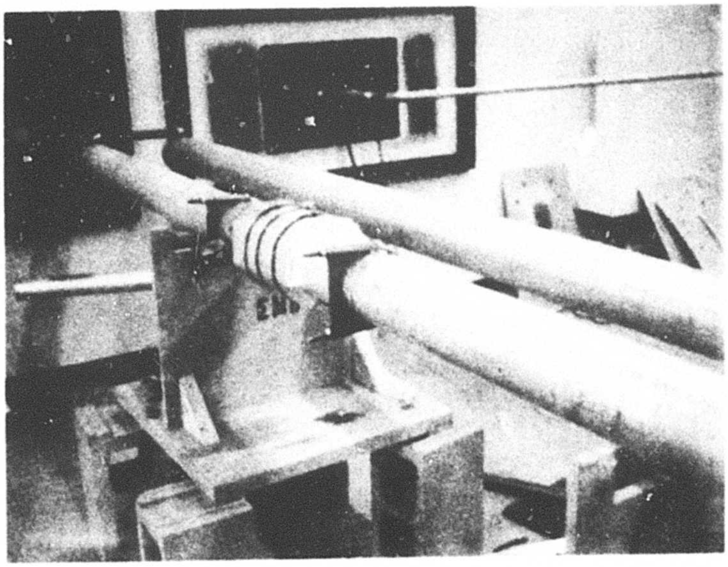

Figure 11. UNF union with 26-gauge sheet steel shroud clamped with muffler clamps.

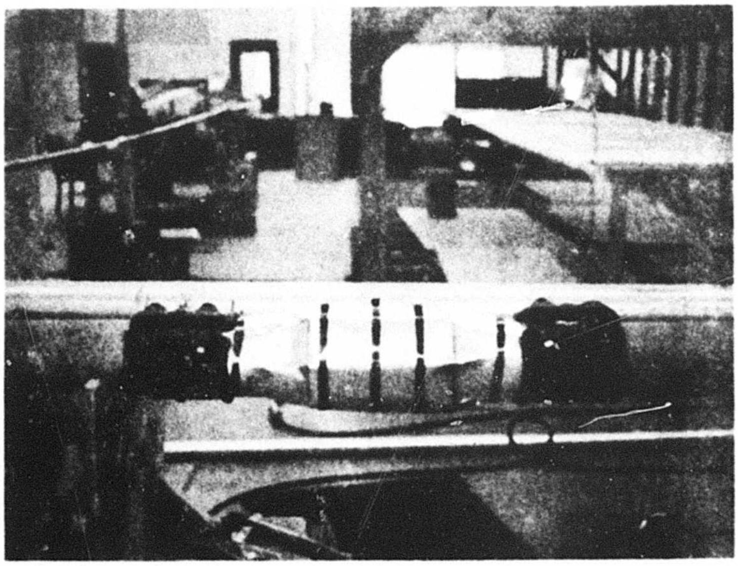

Figure 12. UNF union with 26-gauge sheet steel shroud clamped with Skinner pipe clamps.

26-gauge galvanized sheet steel. For ease of installation, this shroud (hereafter referred to as the Bishop shroud) was constructed in two separate overlapping pieces, each being slightly more than one-half of the circumference of the shroud (Figures 13 and 13[a]). The unit was sized for a snug fit on the conduit--with the center portion large enough to fit over the union. The Bishop shroud was first tested while held in place with several tightly drawn, steel shipping bands. It was also tested with one 5-in. muffler clamp on each end--with each tightened to approximately 30 ft-lb of torque, and with steel shipping bands on the middle section only (Figure 14).

Pipe Clamps. Tests were performed to determine the amount of EMP shielding afforded by completely removing the UNF union and replacing it with either a 6-in. Skinner emergency pipe clamp (Figures 15 and 16) or a PLIDCO* pipe clamp (Figure 17) installed directly on the conduit, with liners inserted between the clamp and the conduit (Figure 18). Most tests were performed with 3-in. wide gaps between the two ends of the conduit inside the clamp. The tests performed with the Skinner clamp were made with the paint removed from the inside of the clamp (thus providing the lowest possible contact resistance between the inside surface of the clamp and the outside surface of the conduit). When installed, the bolts were tightened to a minimum of 80 ft-lb of torque.

The Skinner emergency pipe clamp was tested without a liner, and with the following assortment of liners:

a. 1/16-in. thick aluminum sleeve (same width as clamp [6 in.]).

b. 1/16-in. thick aluminum strip (1 1/2-in. wide) placed longitudinally underneath the gap between the nonhinged edges of the pipe clamp (underneath bolts).

c. Steel wool wrapped around the conduit thread inside the pipe clamp and stuffed in the gap between the nonhinged edges of the clamp (underneath bolts).

d. 28-gauge galvanized sheet steel sleeve (one layer--same width as the clamp).

e. Rubber gasket material** wrapped around the conduit and enclosing the gap between the ends of the conduit inside the clamp.

f. 26-gauge galvanized sheet steel sleeve (three layers--approximately same width as the clamp).

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* PLIDCO split-sleeve pipe clamp for 4-in. pipe, 8 1/2-in. long, with standard BUNA-N packing, distributed by the Pipeline Development Co., Cleveland, OH.

** Tecknit Elastomet, EMI/RFI shielding environmental sealing, convoluted wire in silicone (1/16 in. thick).

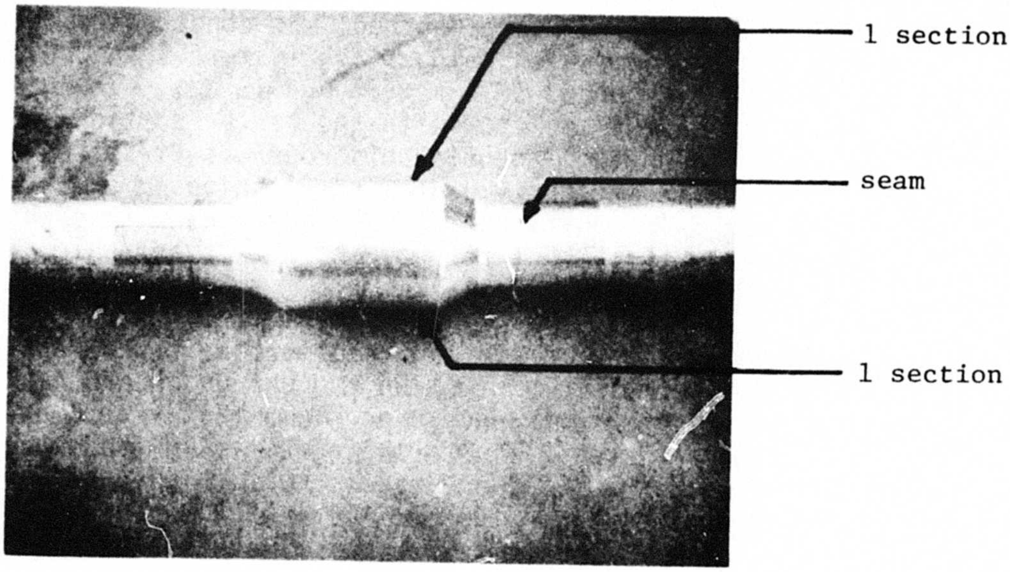

Figure 13. UNF union with Bishop shroud (as received from manufacturer--not clamped).

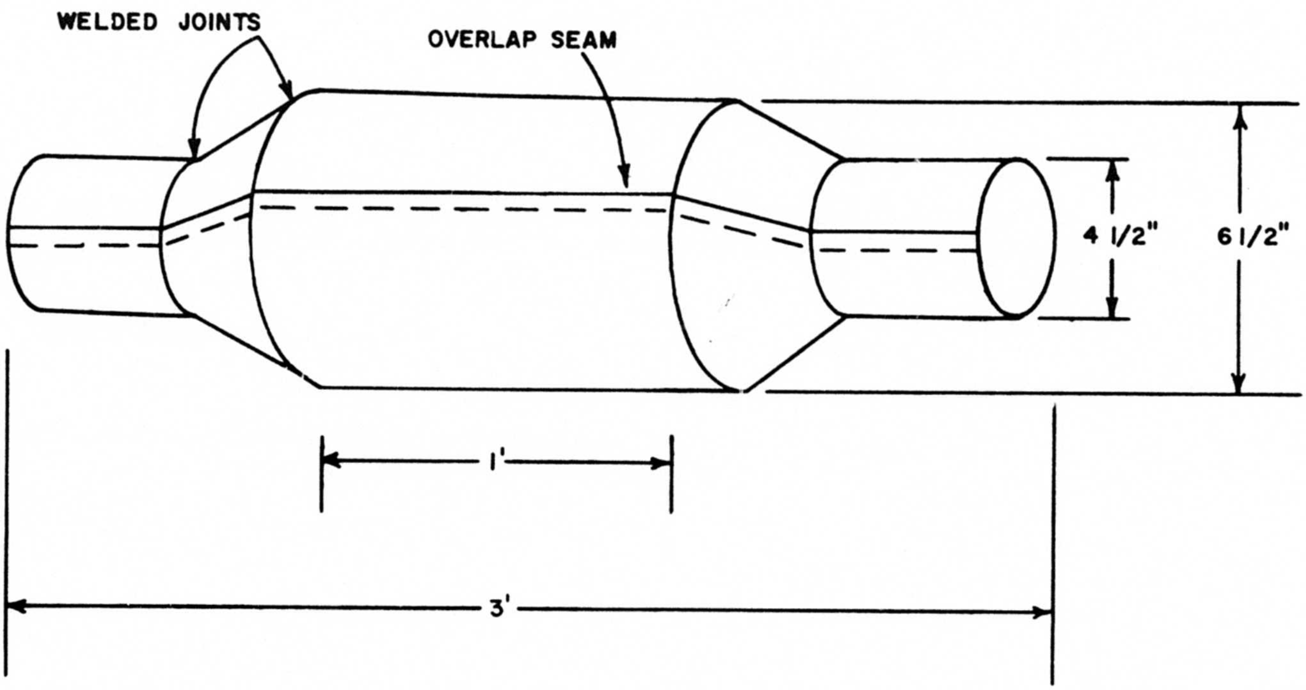

Figure 13a. Bishop shroud UNF union fix.

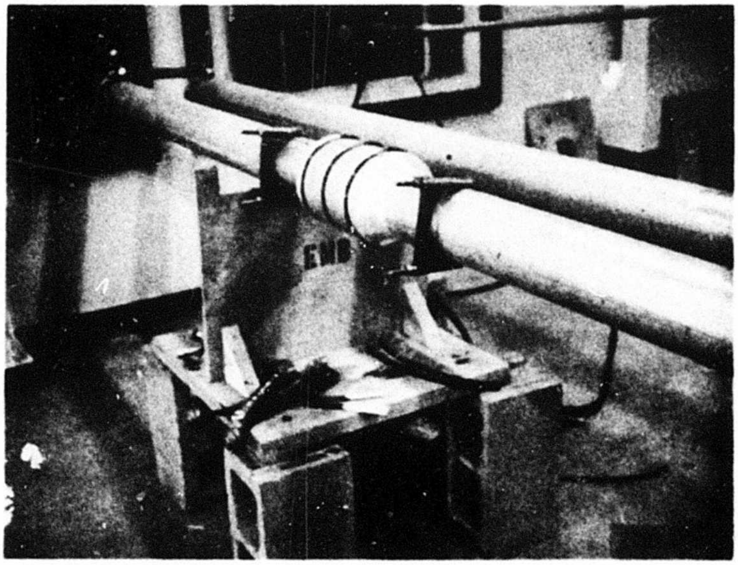

Figure 14. UNF union with Bishop shroud clamped with two muffler clamps.

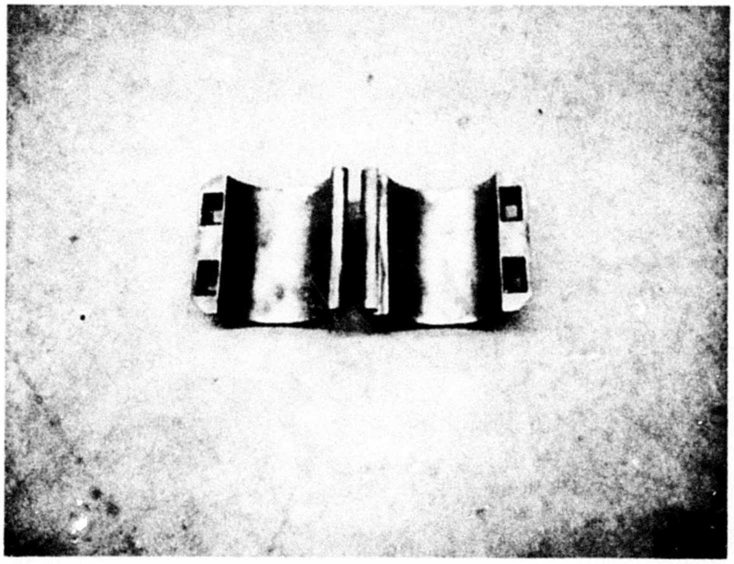

Figure 15. Skinner emergency pipe clamp--open.

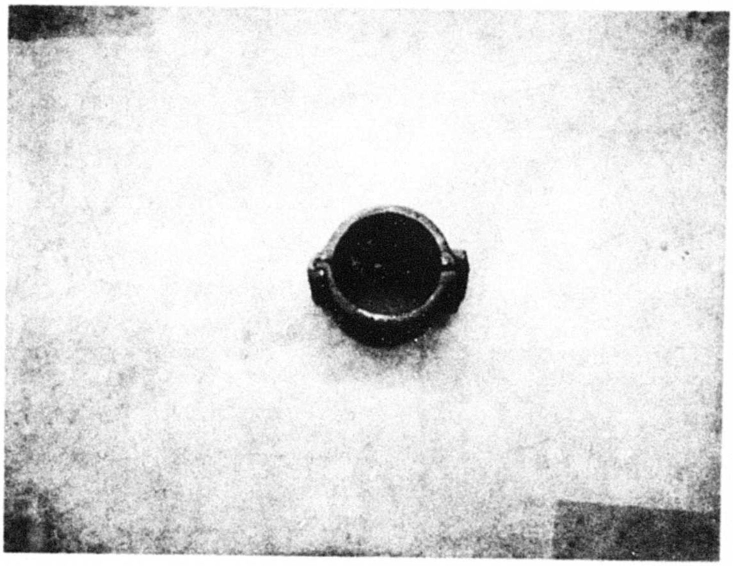

Figure 16. Skinner emergency pipe clamp--closed (but without bolts).

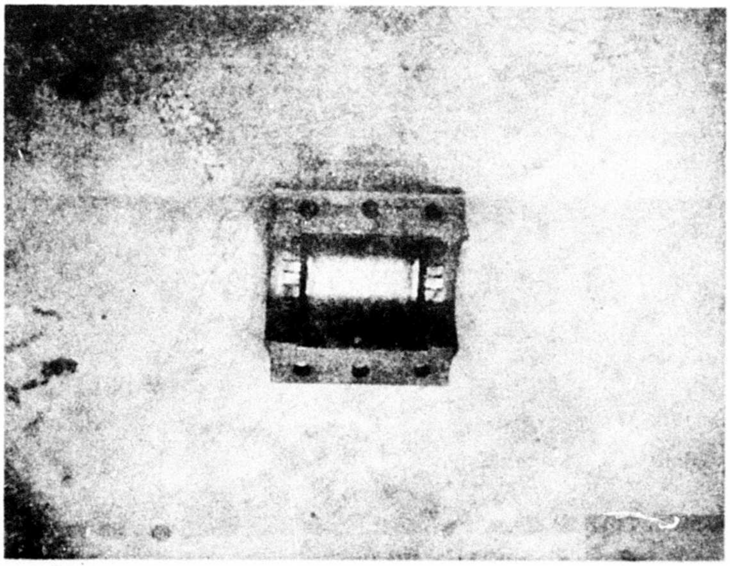

Figure 17. One of two similar halves of a PLIDCO pipe clamp.

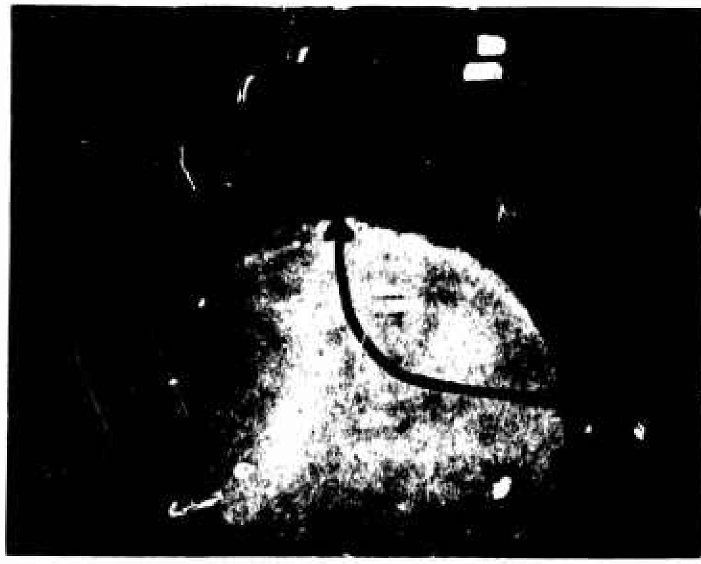

Figure 18. Skinner emergency pipe clamp with sheet steel sleeve as installed.

g. 26-gauge galvanized sheet steel sleeve (two layers--approximately same width as the clamp).

h. 26-gauge galvanized sheet steel sleeve (three layers--approximately same width as the clamp).

i. Eight wire-per-inch galvanized window-screen sleeve (two layers--approximately same width as the clamp).

j. 22-gauge galvanized sheet steel sleeve (one layer--18 in. around and 8 in. wide).

The PLIDCO clamp was tested with the clamp installed on the conduit with no liner (Figure 19) and with a 26-gauge galvanized sheet steel sleeve (two layers--approximately same width as the pipe clamp). In both cases, the paint had been removed from the inside of the pipe clamp.

Test Results

Sealing Compound. It was determined that none of the products distributed by Duro Plastics were sufficiently conductive to make a good fix. Even over distances as small as 1 in., the resistance value of each product was too large to measure using a Simpson 269 VOM. Over a 1-in. distance, the resistance of the metallic-aggregate grout was approximately 15,000 ohms, too large to be useful for EMP shielding.

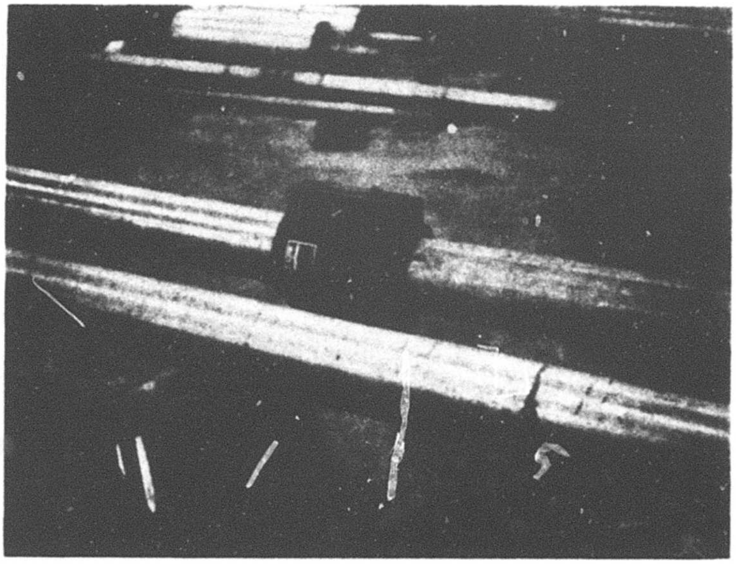

Figure 19. PLIDCO pipe clamp as installed.

For the UNF union with the beads of Tecknit CON/RTV-1, I_{SC} was measured on the sense wire to be 2 amps. However, tests of this same union, at a similar degree of tightness but without the conductive compound beads, resulted in an I_{SC} of 1.2 amps. Thus, it appears that the conductive compound degraded rather than improved the EMP shielding effectiveness of the union. This may have been the result of reduced contact pressure on the union halves or mating surfaces because of the presence of the compound beads. In any case, it was apparent that the Tecknit CON/RTV-1 was not a satisfactory repair.

Shrouds. In order to test the types of shrouds described in previous sections, shrouds were placed over a test conduit containing a leaky union. The test sample consisted of a 10-ft section of 4-in. conduit, with a 4-in. explosion-proof union at the center. The union coupling was hand-tightened enough to provide a large leakage signal. This test sample was subjected to the injected current pulse tests without a shroud and was found to have a short-circuit, sense-wire current of 1 amp. All shrouds tested were placed on this test union, and between tests the unshrouded test union was retested to insure that the leakage current remained at 1 amp.

The various shroud configurations tested were described earlier. Table 1 shows the peak value of the short circuit (I_{SC}) flowing in the sense wire for each of the shroud variations tested. Figures 20 and 21 are typical photographs of the I_{SC} wave form. It should be noted that the major component of I_{SC} for all the shroud materials is a diffusion current. This is as expected because the shroud materials are relatively thin.

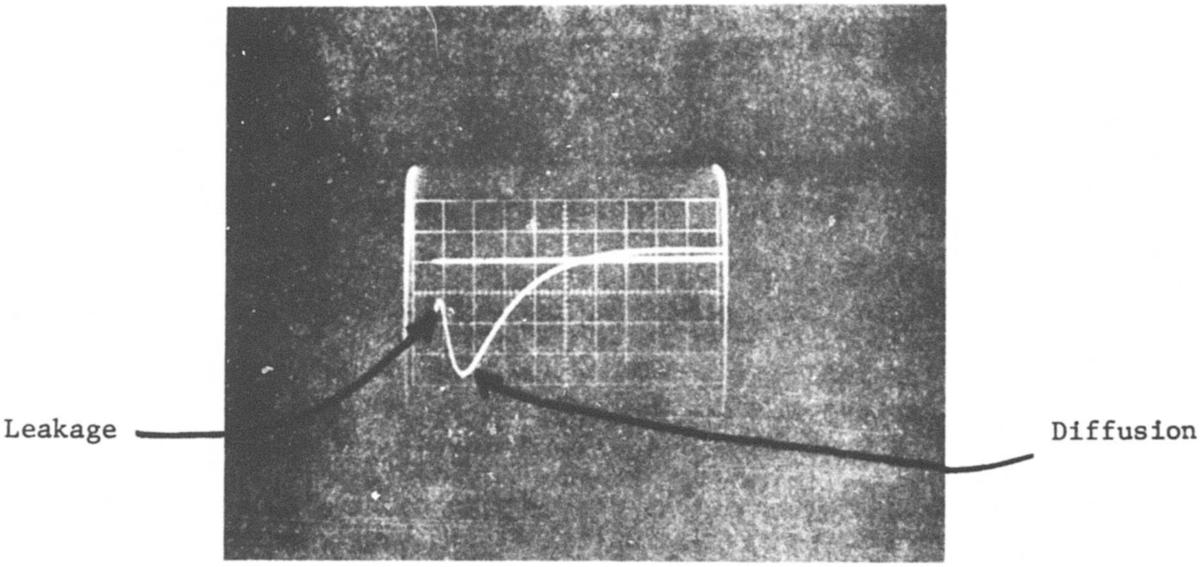

Figure 20. Wave form of I_{sc} during test of 26-gauge sheet steel shroud clamped with two muffler clamps (I = 1 mA/div; t = 200 μsec/div).

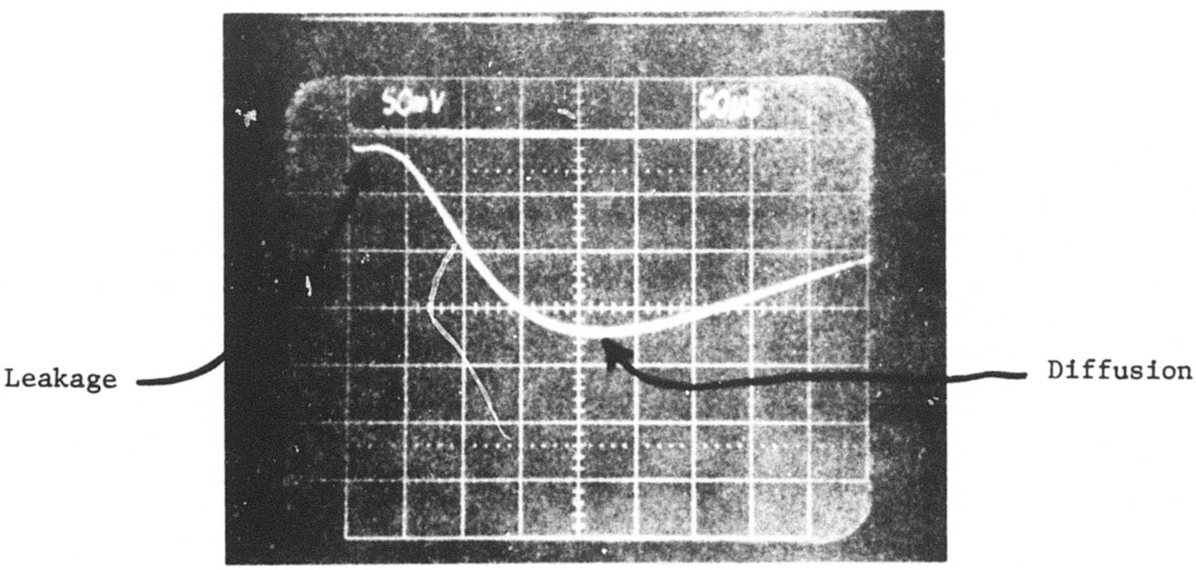

Figure 21. Wave form of I_{sc} during test of Bishop shroud with steel shipping bands (I = 1 mA/div; t = 50 μsec/div).

As stated in the introduction, the goal of this study is to develop a fix that is equivalent to a properly-assembled union that has an I_{SC} for this injected current test of less than 10 mA.[6] From Table 1, samples 8, 10, 11, 12, 13, 14, 15, 17, 18, and 19 all meet the fix criteria, though 8 and 10 are just barely within the limits. Thus, any of these can be considered a fix, and the configuration to be used can be chosen based on other factors, such as ease of installation, cost of materials, resistance to corrosion or deterioration, and the water-sealing properties.

Since the primary component of I_{SC} under these conditions is diffusion current, it is expected that I_{SC} can be reduced by increasing the thickness of the shroud material. However, the shroud material must still be flexible enough so that the clamping system will assure good electrical contact around the total circumference of the conduit. Data from other tests on similar uses of sheet metal as a shielding material, such as the tests on the Skinner emergency pipe clamp with a sheet steel sleeve (which are reported next), indicate that thicknesses up to 22-gauge would be satisfactory for this application.

Pipe Clamps. Table 2 gives the peak value of the short-circuit current (I_{SC}) flowing in the sense wire for each of the pipe-clamp variations. Figures 22 and 23 are typical photographs of this I_{SC} wave form. It should be noted that, unlike the shroud fixes, the major component of I_{SC} for all the pipe clamps is leakage current. This is as expected since the actual conducting material (the walls of the pipe clamp) is relatively thick. The primary source of the leakage current appears to be the gap between the mating surfaces of the two halves of the pipe clamp, the effect of which was greatly reduced by the various liners tested.

Although all but samples 6, 15, and 16 meet the fix criteria for I_{SC}, as shown in Table 2, the Skinner pipe clamp with an aluminum liner (sample 2) and the Skinner clamp with the 22-gauge sheet steel liner (sample 11) provided the most effective EMP shielding (i.e., minimum I_{SC}). However, because of serious corrosion problems (to be discussed in more detail later in this report) that may be encountered because of the junction of the aluminum sleeve with the galvanized surface of the steel conduit and the steel surface of the pipe clamp, it was concluded that the 22-gauge sheet steel liner was the better solution (sample 11).

The data in Table 2 also indicate that, with respect to EMP shielding effectiveness, the gap between the ends of the conduit inside the Skinner pipe clamp (with a 22-gauge galvanized sheet steel liner) was

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[6] D. J. Leverenz, R. G. McCormack, and P. H. Nielsen, *Development and EMP Evaluation of Repairs for 4-In. Explosion-Proof Conduit Unions*, Letter Report E-45 (CERL, July 1973).

Table 1

Results of Injected Current Pulse Tests on Shrouds

	Sample	I_{sc}* (mA)
1.	Hardware cloth (1 layer) + bands	25
2.	Hardware cloth (3 layers) + bands (Fig. 6)	23
3.	Hardware cloth (3 layers) + bands + Skinner Clamps (Fig. 7)	20-23
4.	Hardware cloth + shielding tape + bands (Fig. 8)	14
5.	Hardware cloth + shielding tape + braid + bands (Fig. 9)	11
6.	Hardware cloth + steel wool + bands (Fig. 10)	45
7.	Conetic foil + bands (Fig. 12)	310
8.	Copper screen + bands (Fig. 11)	8.8
9.	26-gauge sheet steel + bands (Fig. 13)	12-13
10.	26-gauge sheet steel + steel wool + bands	8
11.	26-gauge sheet steel + steel wool + 2 muffler clamps + bands (Fig. 14)	3
12.	26-gauge sheet steel + steel wool + 4 muffler clamps + bands	2.4
13.	26-gauge sheet steel + 2 muffler clamps	3.7
14.	26-gauge sheet steel + 2 Skinner clamps (Fig. 15)	2.4
15.	26-gauge sheet steel + 4 muffler clamps	2.7
16.	28-gauge sheet steel + steel wool	10-15
17.	28-gauge sheet steel + steel wool + 2 Skinner clamps	3.4
18.	Bishop shroud (26 gauge)	3.5
19.	Bishop shroud + 2 muffler clamps (Fig. 17)	2.9

*Peak short-circuit current on sense wire.

NOTE: Where a range of values is given, multiple samples were tested in a similar configuration.

Table 2

Results of Injected Current Pulse Tests on Pipe Clamps

	Sample	I_{sc}* (mA)
1.	Skinner pipe clamp	3.8-6.1
2.	Skinner pipe clamp + aluminum liner	0.15-0.2
3.	Skinner pipe clamp + aluminum strip	1.7-5.4
4.	Skinner pipe clamp + steel wool	3.2
5.	Skinner pipe clamp + 28-gauge steel	1.3
6.	Skinner pipe clamp + rubber gasket material	22-42
7.	Skinner pipe clamp + 26-gauge sheet metal liner (1 layer)	0.8
8.	Skinner pipe clamp + 26-gauge sheet metal liner (2 layers)	1.0
9.	Skinner pipe clamp + 26-gauge sheet metal liner (3 layers)	0.95
10.	Skinner pipe clamp + 8 x 8 mesh hardware cloth liner (2 layers)	0.75
11.	Skinner pipe clamp + 22-gauge sheet metal liner (1 layer) - 3-in. gap	0.2-0.5
12.	Skinner pipe clamp + 22-gauge sheet metal liner (1 layer) - 3 1/2-in. gap	0.5
13.	Skinner pipe clamp + 22-gauge sheet metal liner (1 layer) - 4-in. gap	0.5
14.	Skinner pipe clamp + 22-gauge sheet metal liner (1 layer) - 4 1/4-in. gap	1.7
15.	Skinner pipe clamp + 22-gauge sheet metal liner (1 layer) - 5-in. gap	80
16.	PLIDCO pipe clamp	11.2
17.	PLIDCO pipe clamp + 26-gauge sheet metal liner (2 layers)	0.65

* Peak short-circuit current

NOTE: Where a range of values is given, multiple samples were tested in a similar configuration.

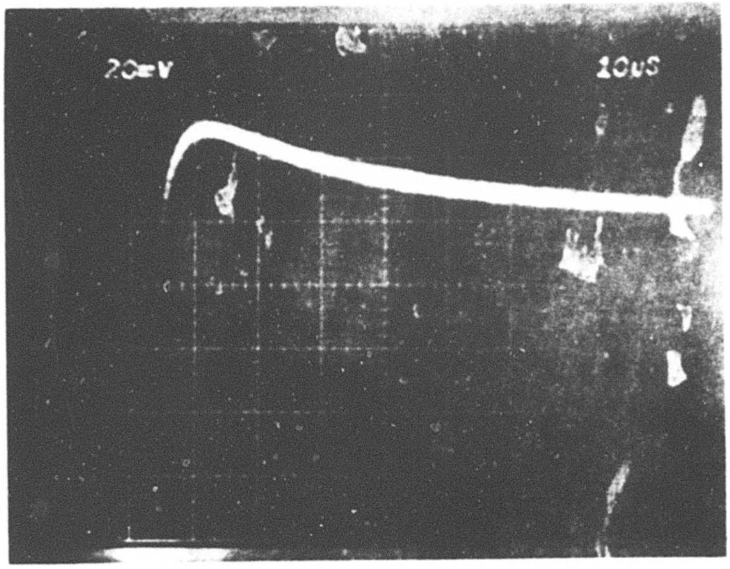

Figure 22. Wave form of I_{sc} during test of Skinner pipe clamp with sleeve of two layers of sheet steel (I = 0.4 mA/div; t = 10 μsec/div.

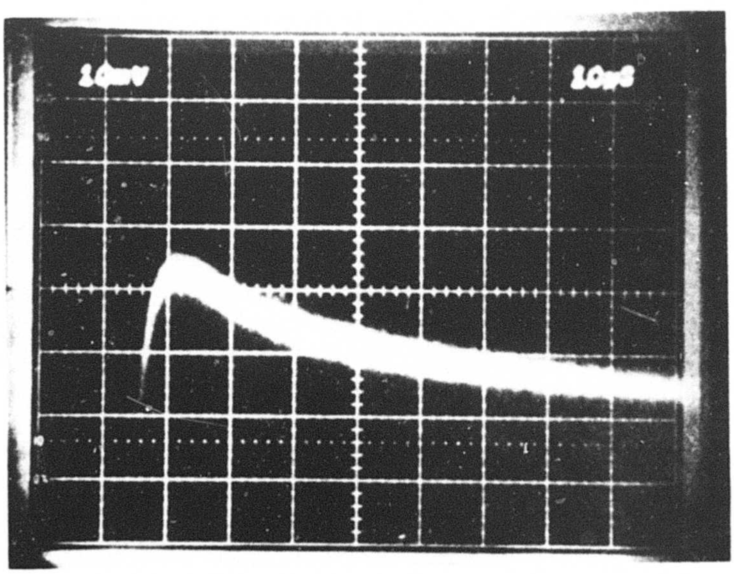

Figure 23. Wave form of I_{sc} during test of PLIDCO pipe clamp with sleeve of two layers of sheet steel (I = 0.2 mA/div; t = 10 μsec/div).

not critical as long as it did not exceed 4 in. It was concluded that, where the union can be removed, a Skinner pipe clamp with a 22-gauge galvanized sheet steel liner provides the best fix.

Mechanical Properties. In addition to the EMP tests, several of the good fixes were also tested to determine their mechanical properties toward tension and lateral-stress forces.

The samples subjected to the tension tests had a 4-in. diameter solid steel plug, approximately 10 in. long, welded into each end of the conduit samples, to which the jaws of an MTS 600,000-lb test machine could be clamped. Each sample was then individually installed in the test machine (Figure 24) and subjected to an increasing longitudinal tension at a constant loading rate of 0.03-in./min until some part of the sample fractured. The amount of tension being applied was recorded throughout the testing of each sample.

Samples subjected to the lateral-stress test were individually installed in a universal test machine (Figures 25 and 26) and subjected to an increasing lateral force (bending force), perpendicular to the cylindrical axis of the conduit sample, until some part of the test sample failed, or, if the sample deflected sufficiently without failing, until the test machine reached the end of its stroke. The load was applied simultaneously on both sides of the test union approximately 15 in. from the center of the union. The amount of force applied to each sample was recorded as a function of machine stroke (i.e., test item deflection).

Three samples were selected for the tension rest: a properly installed UNF union, a Skinner emergency pipe clamp with a 22-gauge galvanized sheet steel sleeve, and a properly installed 4-in. taper-threaded coupling. Each sample consisted of two 13-in. long sections of 4-in. conduit joined by the coupling device to be tested. The Skinner emergency pipe clamp was installed with a liner of 22-gauge galvanized sheet steel (one layer thick) between the clamp inner surface and the conduit outer surface. In addition, the conduit threads and the inside surface of the clamp were coated with Chromerics #4331 conductive compound. The gap spacing between the ends of the conduit inside the clamp was 3 in. The clamp bolts were tightened to 90 ft-lb of torque.

Both the UNF union and the taper-threaded coupling were properly installed in the normal manner, each tightened to a minimum of 600 ft-lb of torque.

Two samples of a properly installed UNF union, a Skinner emergency pipe clamp with a 22-gauge galvanized sheet steel liner, a properly installed 4-in. taper-threaded coupling, and a section of 4-in. conduit without a coupling were selected for the lateral-stress test. One of the UNF union samples was wrench-tight (to a minimum of 300 ft-lb of

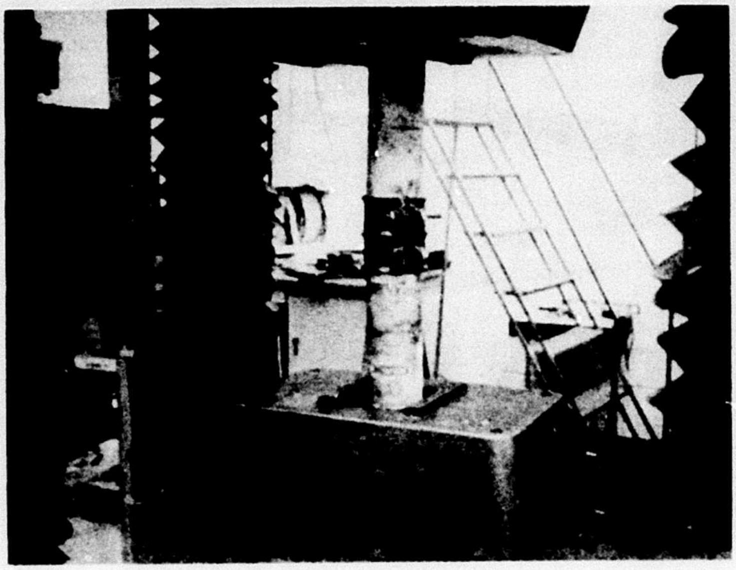

Figure 24. Universal test machine used for tension tests.

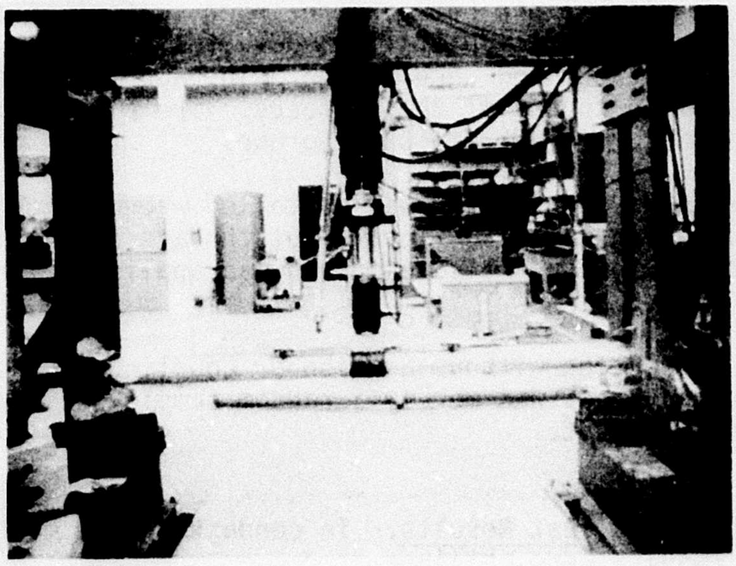

Figure 25. Universal test machine used for lateral-stress tests.

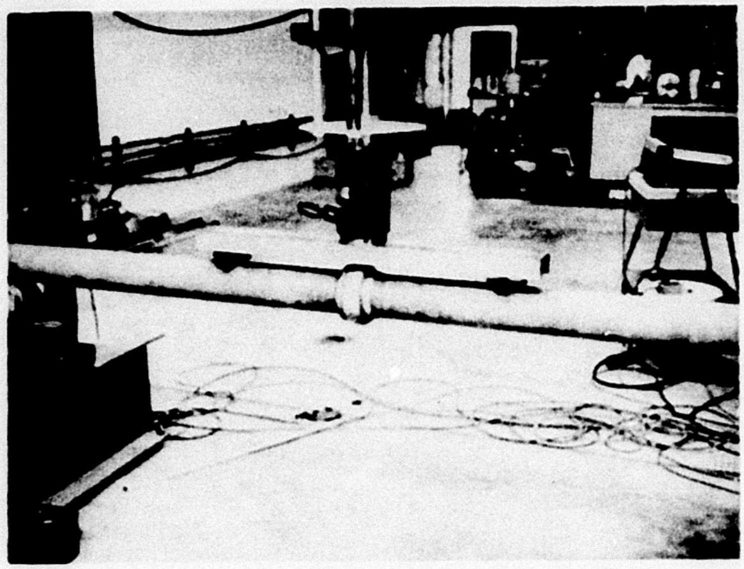

Figure 26. Lateral stress being applied to UNF union test sample.

torque), while the other was tightened to approximately 1200 ft-lb of torque. In both cases, the conduit was mated with the union using the factory-cut threads and no conductive compound was applied.

The Skinner emergency pipe clamp was installed with a 22-gauge galvanized sheet steel liner between the inner surface of the clamp and the outer surface of the conduit. The ends of the conduit inside the clamp were both threaded and were spaced 3 in. apart. No conductive material was applied to any of the surfaces. The pipe-clamp bolts were tightened to a minimum of 90 ft-lb of torque.

The taper-threaded coupling was installed wrench-tight in the normal manner, mating with the factory-cut threads on each of the two conduit sections. No conductive compound was applied to the mating threads.

The conduit section without a union or coupling was not specially prepared in any way, but was merely a random sample of 4-in. rigid galvanized steel conduit.

Mechanical Properties Test Results. In conducting the mechanical tests, the following results were obtained.

One of the conduit sections was pulled from the Skinner emergency pipe clamp when 8530 lb of tension was applied. There appeared to be no significant resulting physical damage to either the clamp or the conduit.

The UNF union failed when 55,060 lb of tension was applied. As shown in Figure 27, the interior-beveled, retainer-ring portion of the union casting fractured, allowing the conduit to pull free of the union.

The 4-in. taper-tapped coupling failed when 74,290 lb of tension was applied. As shown in Figure 28, the conduit fractured along one of the threads, allowing it to pull free of the coupling.

The figure of merit derived from the lateral-stress deformation test for each of the test samples is referred to as the ultimate moment (M_μ) and is calculated using the following relationship:

$$M_\mu = (P_\mu/2)(L/2 - a)$$

where (Figure 29)

P_μ = ultimate test load, or maximum force applied to the sample by the test machine (read directly from the machine's digital readout)

L = unsupported length of distance between the sample's two points points of support

a = load-point spacing, or distance between the points where force was applied to each sample.

Table 3 lists the values of M_μ, P_μ, L, and a for each sample tested. As shown, the Skinner emergency pipe clamp presented the least resistance to failure from a laterally applied load.

Photographs and notes were made of the mode of failure of each sample. Figures 30 and 31 show that the wrench-tight UNF union failed when the conduit pulled loose from the union threads on the retainer-ring end of the union. The UNF union that was tightened to 1200 ft-lb of torque failed when the conduit pulled loose from the other end of the union (Figures 32 and 33). Except for thread damage, there was no damage to the union on either sample.

Figures 34 and 35 show the failure mode of the Skinner emergency pipe clamp. When the conduit pulled free of the pipe clamp, the only appreciable damage that was noted occurred to the 22-gauge galvanized sheet metal sleeve (Figures 36, 37, and 38).

As shown in Figures 39 and 40, the taper-tapped coupling sample failed when the conduit fractured. Figure 41 shows the plain conduit sample after it had been deflected to the limit of the stroke of the test machine.

<u>Corrosion/Waterproofing</u>. Because serious corrosion is possible at dissimilar metal junctions, the preferred fixes are those that avoid any

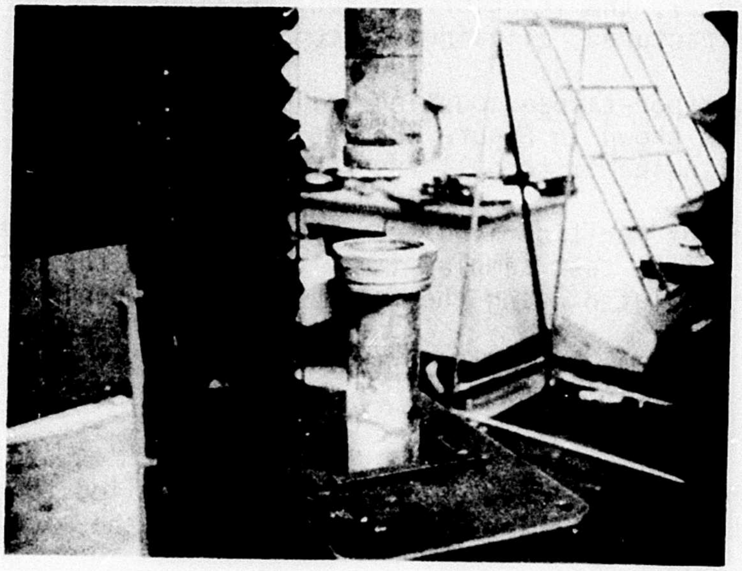

Figure 27. UNF union sample after tension test.

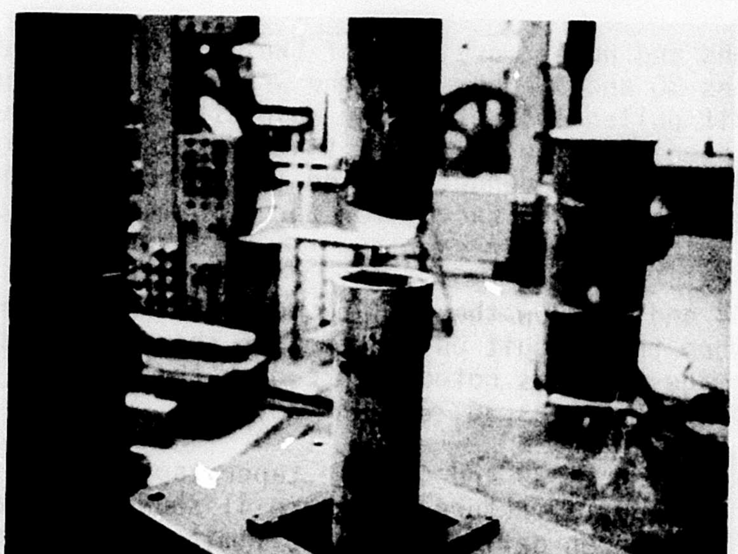

Figure 28. Taper-tapped coupling sample afer tension test.

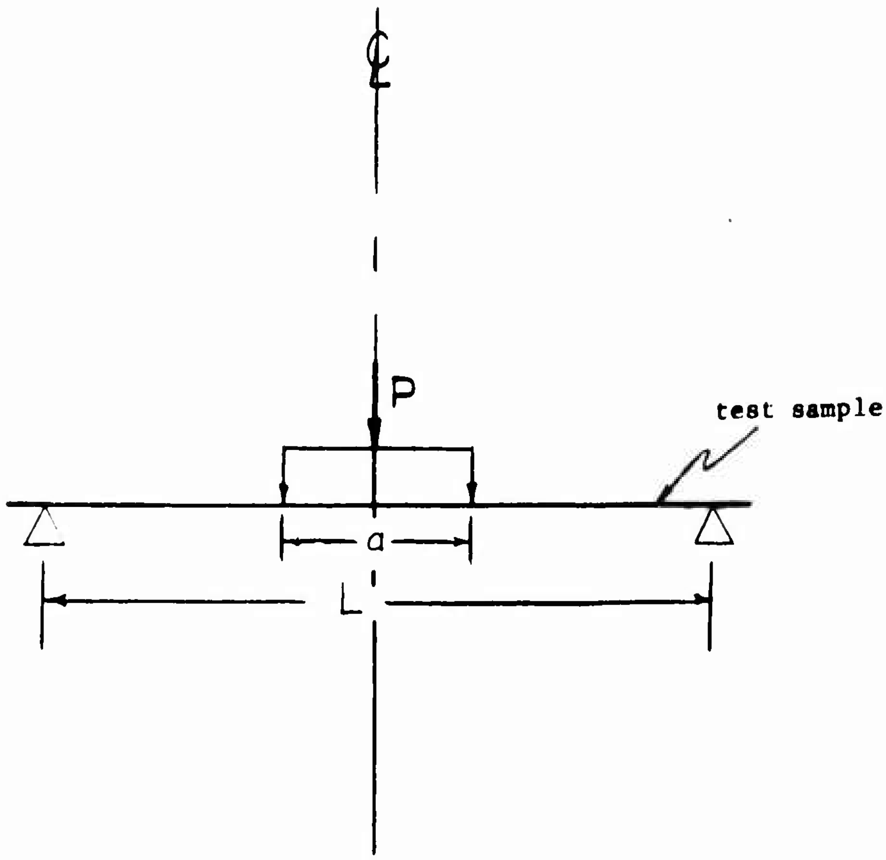

Figure 29. Test parameters for lateral-stress test.

Table 3

Numerical Results of Lateral-Stress Test

Sample Description	M_μ (in.-lb)	P_μ (lb)	L (in.)	a (in.)
UNF union--wrench-tight	106,680	6720	93.5	30
UNF union--1200 ft-lb torque	84,656	5291	94.0	30
Skinner pipe clamp with liner	25,472	1592	94.0	30
Taper-tapped coupling	117,397	7323	94.125	30
Conduit alone	134,903	8418	94.125	30

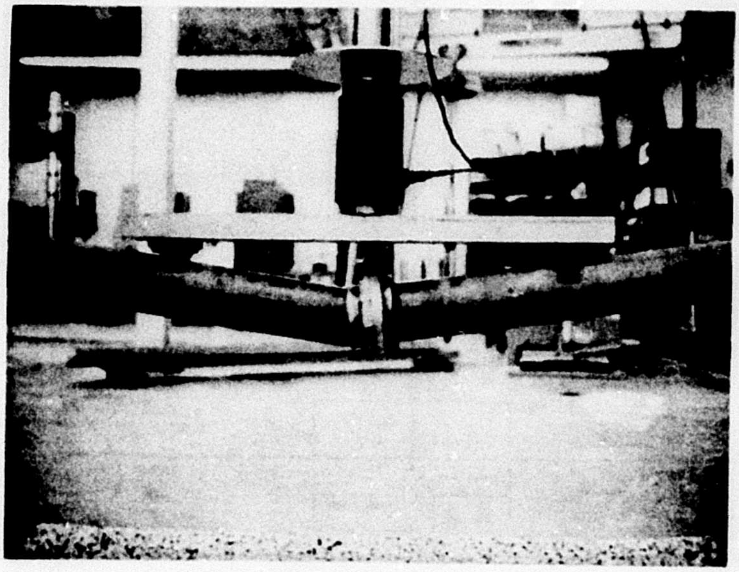

Figure 30. Side view of UNF union wrench-tight sample after lateral-stress test.

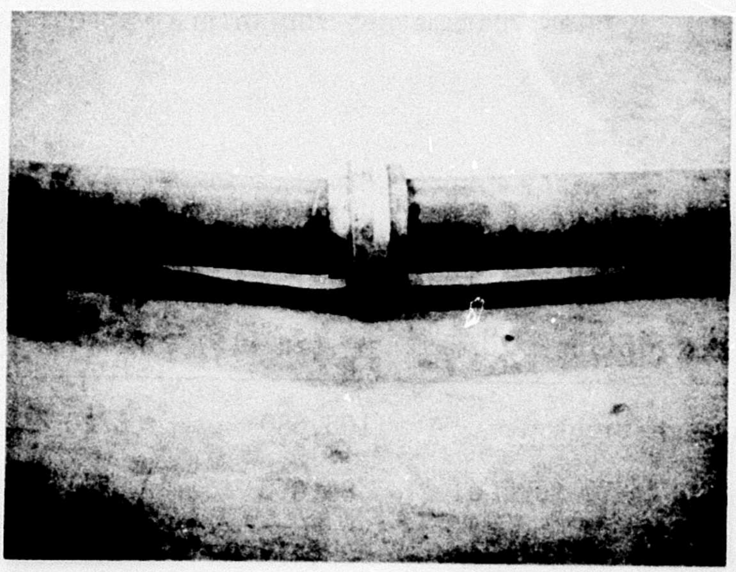

Figure 31. Bottom view of UNF union wrench-tight sample after lateral-stress test.

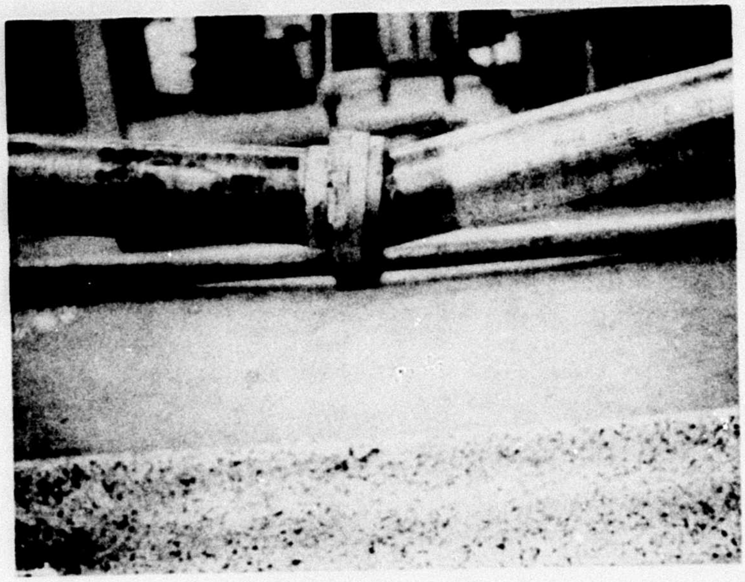

Figure 32. Side view of UNF union 1200 ft-lb sample after lateral-stress test.

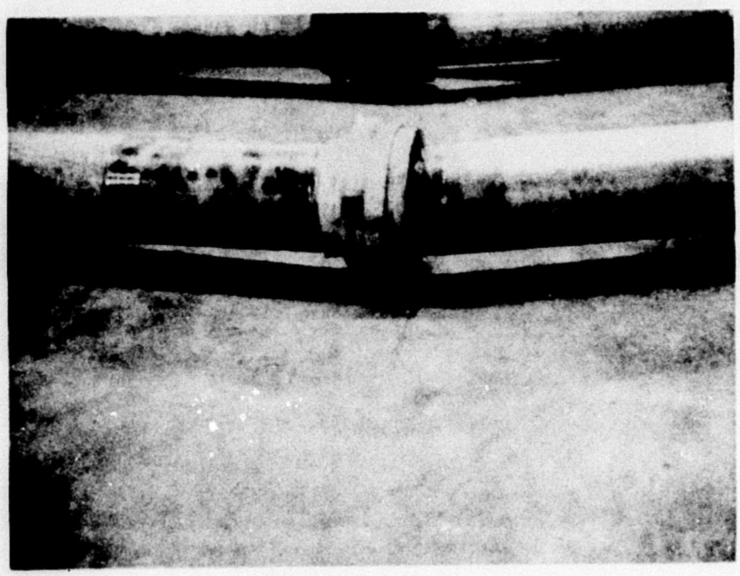

Figure 33. Bottom view of UNF union 1200 ft-lb sample after lateral-stress test.

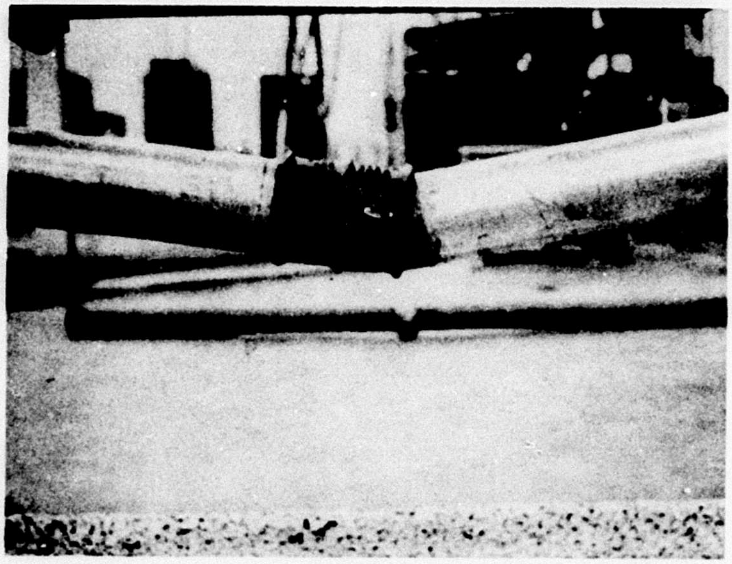

Figure 34. Side view of Skinner pipe clamp with sheet steel sleeve sample after lateral-stress test.

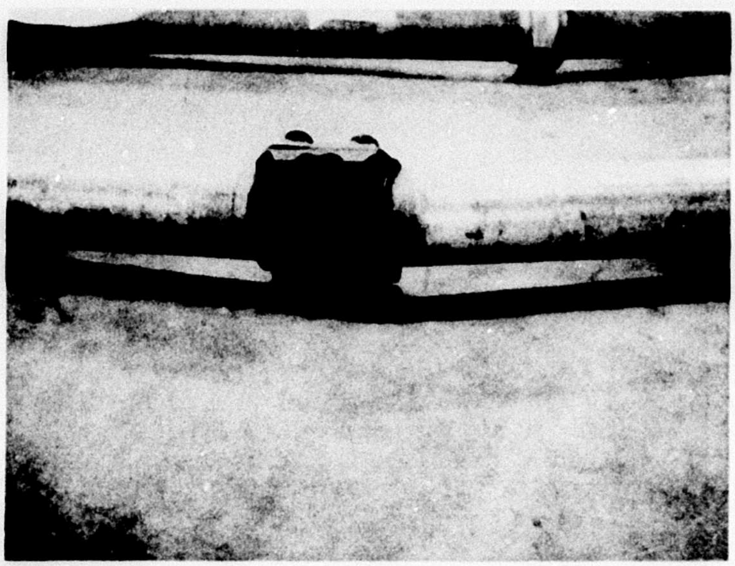

Figure 35. Bottom view of Skinner pipe clamp with sheet metal sleeve sample after lateral-stress test.

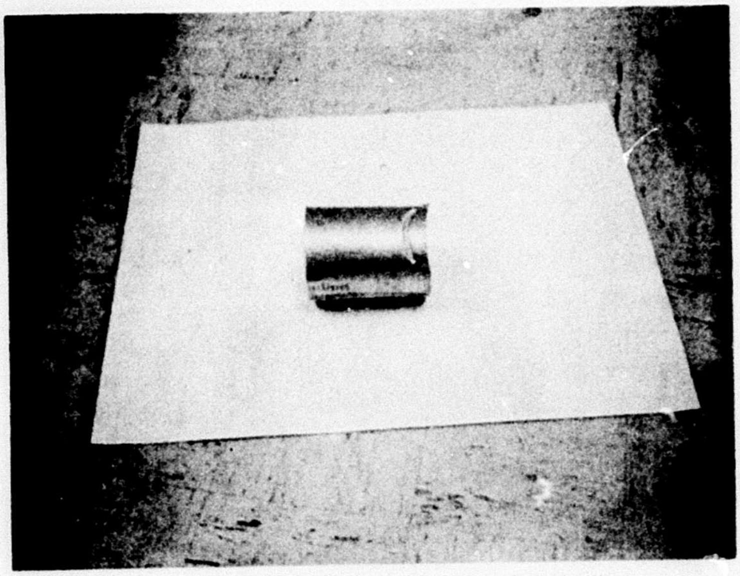

Figure 36. Sheet steel sleeve from Skinner pipe-clamp sample after lateral-stress test.

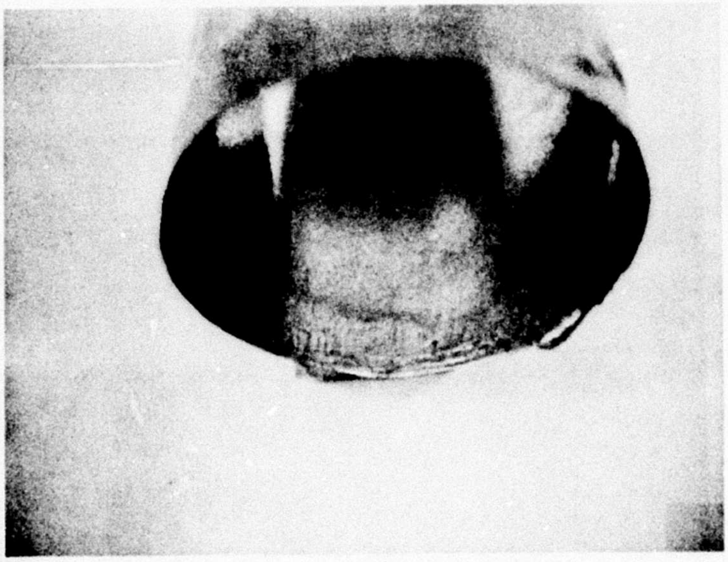

Figure 37. End of sheet steel sleeve from Skinner pipe-clamp sample from which conduit pulled free during lateral-stress test--showing scoring by conduit threads.

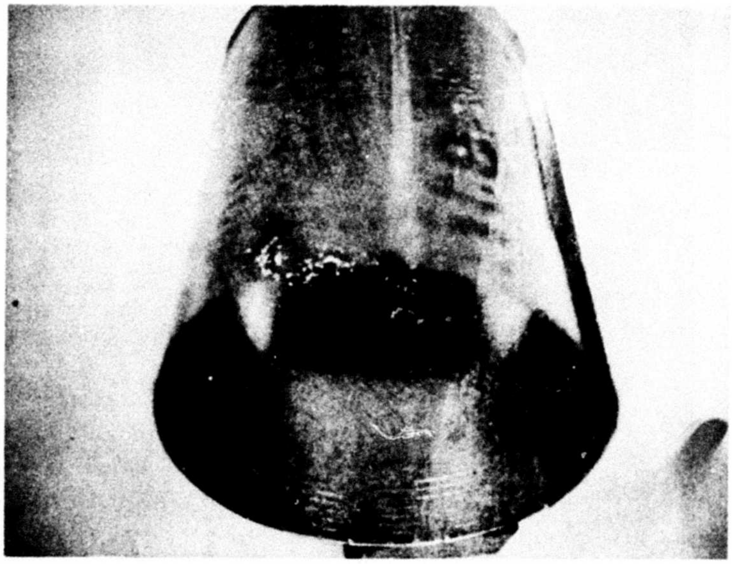

Figure 38. End of sheet metal sleeve from Skinner pipe-clamp sample in which conduit remained secure during lateral-stress test--showing scoring by conduit threads.

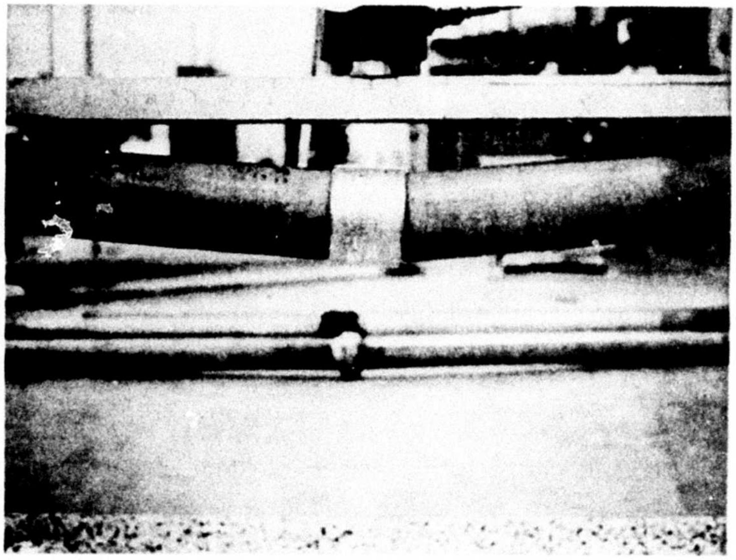

Figure 39. Side view of taper-tapped coupling sample after lateral-stress test.

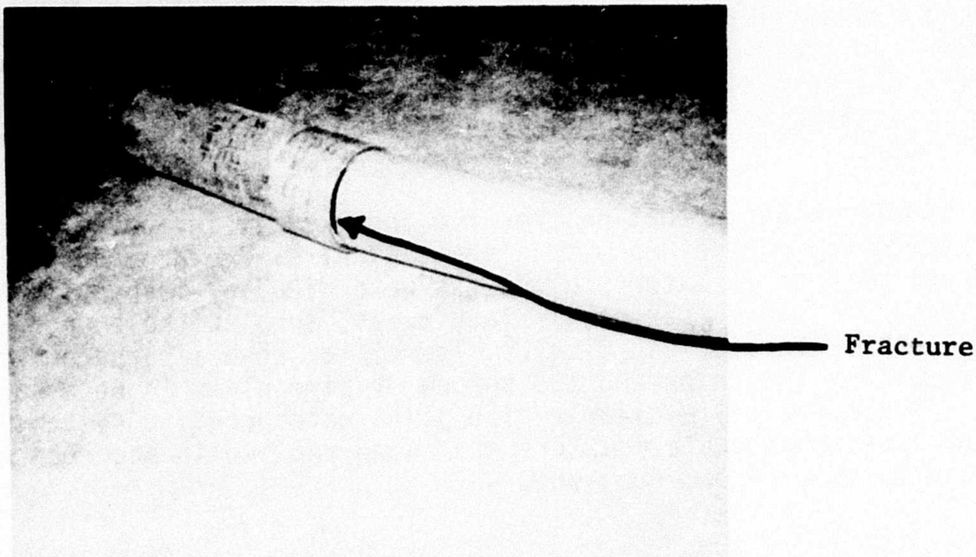

Figure 40. Bottom view of taper-tapped coupling sample after lateral-stress test--showing conduit wall fracture.

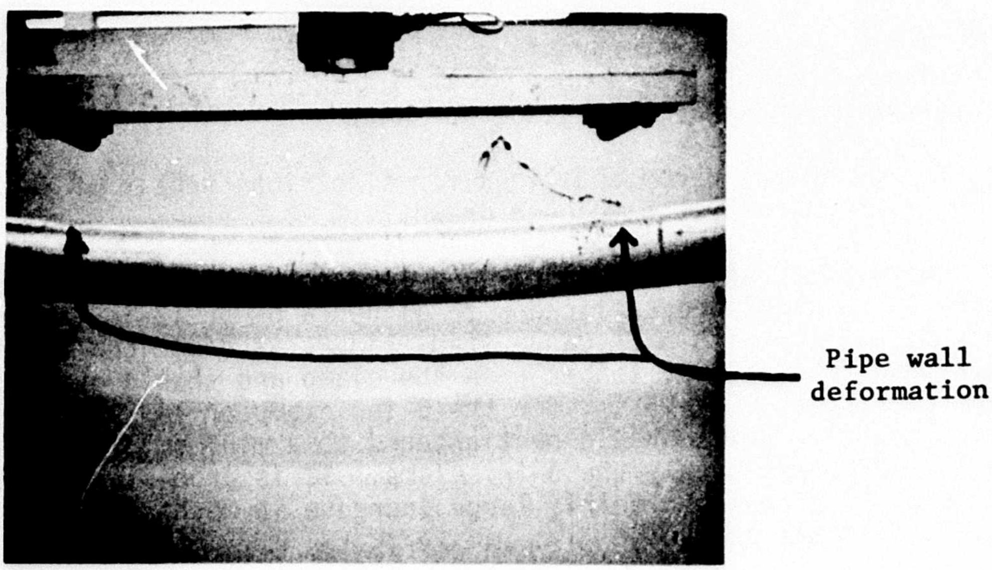

Figure 41. Side view of continuous conduit sample after lateral-stress test--showing conduit wall deformation.

unnecessary dissimilar metal junctions. Standard cathodic-protection techniques are still required to minimize the remaining potential for corrosion. In addition, metal-to-metal junctions must be protected from moisture. Any corrosion of these junctions will degrade their electrical contact resistance and result in a degradation of the EMP shielding effectiveness.

It should be noted that neither the sheet steel shroud nor the Skinner emergency pipe clamp with a sheet steel sleeve provide any significant measure of waterproofing (as determined by inspection and by performing a limited number of air leak tests, such as those used by Bell Telephone Laboratories [BTL]).[7] Therefore, some alternate method of waterproofing the union and the shroud or pipe clamp is necessary. Table 4 lists currently available pipe joint waterproofing systems which should provide an adequate moisture seal when applied in accordance with the manufacturer's recommendations.

<u>Conclusions and Recommendations</u>. Study results indicate that the leakage signal due to a defective union can be reduced to that of a properly assembled union with the use of a 26-gauge or heavier sheet steel shroud that entirely covers the union and is securely attached to the conduit for good electrical contact. It is also possible to obtain similar electrical results by replacing the union with a Skinner emergency pipe clamp and using a sheet steel liner. The resistance to mechanical failure was considerably less with the Skinner pipe clamp than with a normally installed union (8500 lb vs 55,000 lb tension and 25,500 in.-lb lateral moment for the Skinner clamp vs 84,650 for the union).

Additional separate waterproofing will be necessary for any of the fixes developed in the study. None of the conductive sealing compounds tested are useful in reducing leakage current.

The following are recommendations for electrical repair of faulty unions in which the cables have been drawn:

a. Where possible, the defective union should be removed by cutting. The union should be replaced with either a 6- or 12-in. Skinner emergency pipe clamp with a 22-gauge steel liner, as described earlier. The liner should be 1-2 in. longer than the clamp and should overlap a minimum of 1/2 in. (8 x 15 in. for the 6-in. clamp or 14 x 15 in. for the 12-in. clamp). Bolts should be tightened to a minimum of 80-90 ft-lb of torque. CERL tested only the 6-in. clamp. It is probable that the 12-in. clamp would supply a fairly large increase in mechanical strength at little additional cost.

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[7] R. F. Glaser, *EMP/Air-Flow Correlation Tests--Clean Appleton Unions*, Memorandum for File (Bell Laboratories, April 1973).

Table 4

Pipe Joint Waterproofing Systems

Material	#	Trade Name	Type of Product	Cost $	Manufacturer
Tape	1	Plicoflex #340 PVC-Pipeline Tape	PVC Backing and Butyl Rubber Mastic	6.90 - 9.45/100 sq ft	Cathodic Protection Service
Primer	2	Plicoflex Primer #105	-	2.40/gal	4601 Standford Street
Mastic	3	Polymastic #455	Butyl Rubber Mastic	5.25/gal	Houston, TX 77066
					1-713-526-1981
Tape	4	Scotchrap Vinyl Mastic Tape Seal No. 3	Vinyl Back and Butyl	25.00/100 sq ft	3M Company
Primer	5	Scotchrap Pipe Primer	Butyl Type	4.30/gal	Dielectric Materials and Systems Department
Putty	6	Scotchrap Pipe Putty	Rubber Base, Flexible	1.18/box	3M Center-224-64
				1/4-in. x 60 ft bead	St. Paul, MN 55101
					1-612-733-1656
Tape	7	Polyken #930-35 Joint Wrap	Polyethylene and Butyl Rubber Adhesive	17.65/100 sq ft	Polyken Division
Primer	8	Polyken #927 Primer	Butyl Type	5.25/gal	Kendal Company
Finish Tape	9	Rock-Shield #955-20	Polyethylene and Adhesive	6.00/100 sq ft	20 Walnut Street Wellesley Hills, MA 02181
					1-617-237-5400

Table 4 (cont'd)

Material	#	Trade Name	Type of Product	Cost $	Manufacturer
Tape	10	Protecto Wrap #200	PVC and Coal Tar Resin	15.87/100 sq ft	Protecto Wrap Company
Primer	11	Protecto Wrap #1170 Primer	-	3.55/gal	2255 S. Delaware Street
Mastic	12	CA1200 Coating	Coal Tar Resin	4.87/gal	Denver, CO 80223
					1-303-777-3001
Heat-Skrinkable Sleeve	13	Thermofit GRS6-24 Kit	Sleeve-Hi Density Polyethylene/Mastic	26.82/ea	Raychem Corporation
Channel			Stainless Steel Flexible Closure Channel	In lot of 40	300 Constitution Drive
Strip			Profile Strip and S1012 Mastic		Menlo Park, CA 94025
					1-415-329-3238 1-312-437-8880(Chicago Of)
Tape	14	Tapecoat CT	Polyethylene and Coal Tar Resin	24.00/100 sq ft	Tapecoat Co., Inc.
Mastic	15	TC Mastic	Coal Tar, Resins and Fillers	6.80/gal	1527 Lyons Street
or					Evanston, IL 60204
Tape, Hot-Applied	16	Tapecoat 20	Fabric Satur. with Coal Tar Pitch, Polyester Film	26.00/100 sq ft	1-312-866-8500

b. When the faulty union cannot be removed, a preformed shroud (such as the Bishop shroud) should be installed over it. The two-piece shroud design requires very little space for installation. The material should be a 22- or 26-gauge galvanized sheet metal and the method of attachment should be as in Figure 14, with large muffler clamps supplying pressure around the periphery of the shroud. The larger center portion of the shroud should be held together with a minimum of three steel bands or three screwdriver-adjusted hose clamps.

3 DEVELOPMENT AND EMP EVALUATION OF COVERS FOR COMMUNICATIONS CABLE-GRIPPER BOXES

Background. Cable gripper and splicing boxes were installed in many of the conduit runs. Each box was fabricated from two sections of 4-in. rigid-steel conduit and two 8 1/2-in. diameter discs cut from 1 1/4-in. thick commercial-grade steel plate. The discs have 4-in. diameter holes in the center to allow them to fit over the end of a 4-in. conduit section. The discs are fillet-welded to the conduit ends. Conduit sections are installed in the conduit runs so that the discs face each other, separated by approximately 12 to 15 in. The discs and conduit are held in mechanical alignment by three 3/4-in. bolts that pass through both discs. The space between the two discs forms a cylindrical volume in which cables are spliced or grippers are attached to provide strain relief. Unfortunately, no satisfactory method was available for enclosing this cylindrical volume to provide sufficient shielding from the effects of EMP. The method would not only have to provide adequate EMP shielding, but also allow for quick and easy field installation (without excessive prior training of the field crews), with a minimum of expense, special item design, or procurement effort.

The SAFEGUARD System Command (SAFSCOM) requested that CERL develop and test a wrap-around shroud and clamping system for enclosing the cable-gripper boxes that would meet the following criteria:

a. Allow easy installation by field crews.

b. Provide adequate shielding against EMP induced signals on wires routed through the gripper boxes. (Acceptable shielding levels, as established by SAFSCOM, were that the shielding provided should be equivalent to that of wrench-tightened UNF unions--10 mA or less).

c. Require inexpensive materials and hardware that are readily available through normal U. S. Government procurement channels.

It was also requested that since the field-installed boxes would have 3/4-in. bolts through the end discs, that test data be provided showing the effects of this bolt penetration.

Approach. Experience and data previously obtained by CERL during similar test projects (see Chapter 2) indicated that some form of lightweight, rolled sheet metal shroud might satisfy the requirements. Data from earlier tests indicated that one of the most important goals in installing a shroud is to minimize the contact resistance between the shroud material and the surface to which it is clamped. It is also important to have a continuous surface-area contact between the shroud material and the mating surface. The thickness and shielding ability of the shroud material itself also affect the EMP shielding effectiveness of the resulting shroud installation. The thicker the shroud material, the better its shielding characteristics, but the more difficult it is to apply sufficient clamping pressure to obtain continuous surface contact and thus minimum contact resistance. Previous CERL efforts have focused on determining the best balance between minimum contact resistance and maximum shielding ability of the shroud material (Chapter 2). Based on this experience, 22- and 26-gauge sheet metal were chosen to fabricate the test shrouds. The use of a different number of layers of metal and different methods of clamping the shroud material to the edge of the steel discs were investigated. In all cases, extreme care was taken to insure that the mating surfaces were clean and smooth.

Test Procedures. The EMP shielding effectiveness of each shroud and clamp combination was evaluated using the injected current pulse technique. This technique is the same as used in previous CERL conduit tests.[8]

Basically, the test setup consisted of two 10-ft conduits that formed a parallel conduit transmission line with the test sample in one leg. A pulser injected into the transmission line a current pulse that had a 3-ns rise time, 150-amp peak, and an exponential decay with a time constant of 4 μsec. A sense wire was pulled through the test conduit and shorted to the conduit at both ends.

An oscilloscope with a current probe was used to monitor the signal induced in the sense wire (I_{SC}) by the injected-current pulses.

Test Samples. The gripper box was fabricated from a 4-in. steel conduit and two 8 1/2-in. diameter by 1 1/4-in. thick steel discs (Figure 42). The discs were welded to the conduit using a fillet weld on each side (Figures 43 and 44). The resulting disc conduit sections were then installed in the 4-in. steel-conduit transmission line so that the discs were parallel and 12 in. apart. Test shrouds were then installed on this test cable-gripper box.

[8] D. J. Leverenz, R. G. McCormack, and P. H. Nielsen, *The Effect of Conduit Coupling Conditions on the EMP Shielding of Conduit Joints*, Letter Report E-4 (CERL, July 1972).

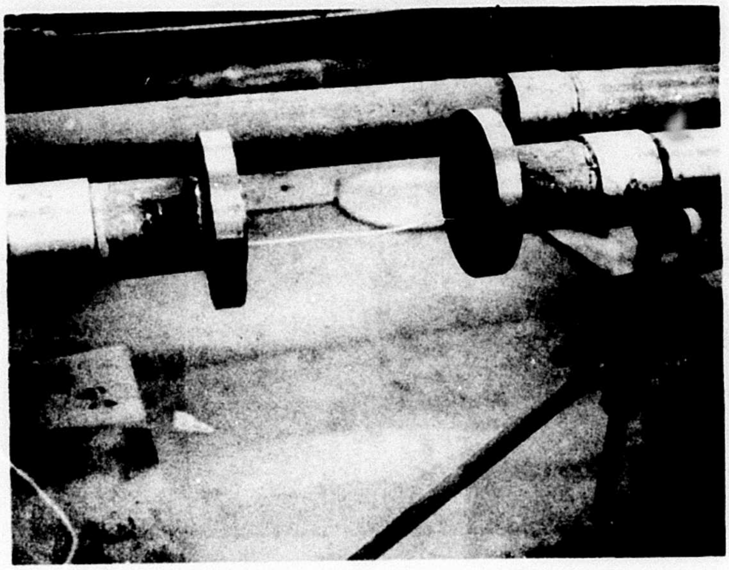

Figure 42. Test setup showing cable-gripper box ends installed in 4-in. conduit.

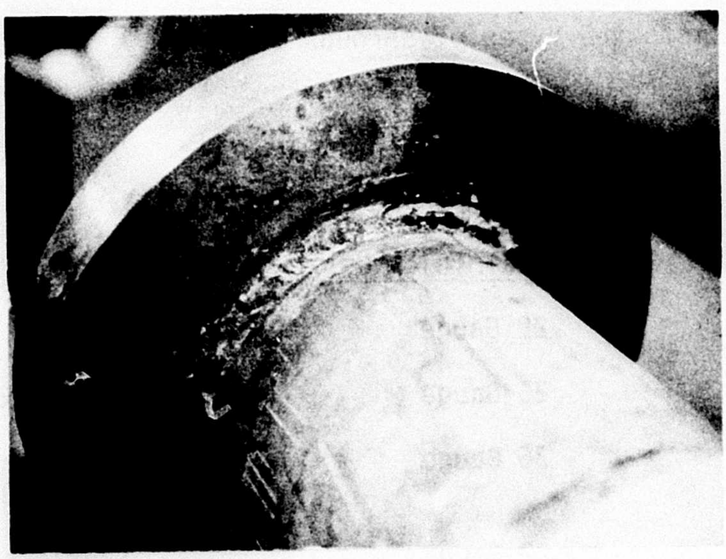

Figure 43. Cable-gripper box disc welded to 4-in. conduit.

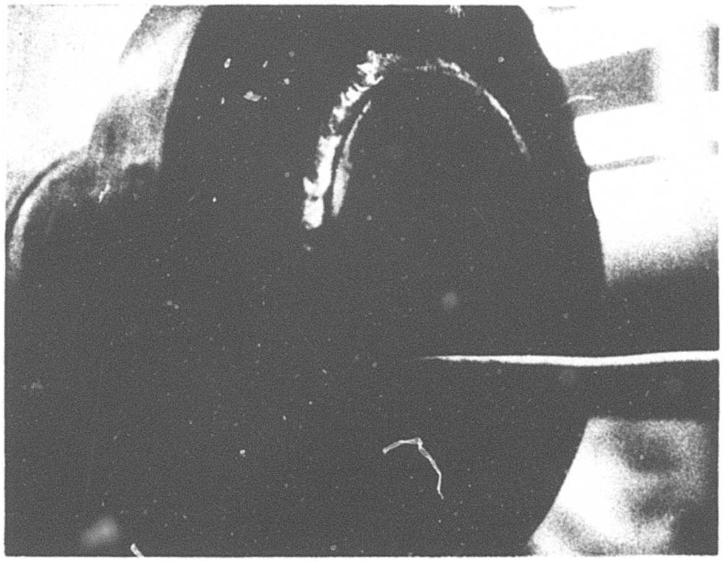

Figure 44. Cable-gripper box disc showing inside weld to 4-in. conduit.

The galvanized steel, sheet metal shrouds were installed so that the maximum possible metal-to-metal contact occurred between them and the steel discs. In each case, the clamping device was tightened to a maximum.

Table 5 lists the types of shrouds tested.

Table 5

Types of Shrouds Tested

# of Layers	Material Thickness	Shroud Material Size
1	22 Gauge	15 x 23.25 in.
	26 Gauge	15.375 x 38.5 in.
2	26 Gauge	Two separate sheets, 14.5 x 38.5 in.
3	22 Gauge	Single sheet, 15 x 96 in.
	26 Gauge	Three separate sheets (26 gauge) listed above

These shrouds were installed by wrapping the material around the discs of the gripper box so that the smallest dimension of each sheet of material was the length of the resulting cylindrical section. In each case, the metal sheets were rolled prior to installation to assure conformity to the contour of the steel discs.

The following clamping devices were evaluated:

a. Standard automotive, stainless-steel, screw type hose clamps, referred to later as hose clamps (Figure 45).

b. Metal shipping bands,* referred to later as shipping bands, which were installed as tightly as possible with the banding machine** (Figure 46).

c. Locally manufactured clamps, referred to later as CERL clamps, fabricated from 29 by 1 1/4 by 1/16-in. thick steel banding (Figure 47).

Test Results. Figures 48 through 52 show a series of oscilloscope wave form photographs of the sense-wire, short-circuit current for a single-layer, 26-gauge shroud held with hose clamps. Various time bases are portrayed to show all rise and fall times of interest. Since these wave forms are typical of those for all shroud configurations, only this series is presented herein.

The double-peaked response shown in Figures 48 through 52 is typical. The first peak occurred approximately 2 or 3 μs after the current pulse was injected; the second peak occurred somewhat later (up to 340 μs after the current pulse was injected). The first peak, the leakage-current component (I_L), is primarily due to discontinuities in the metal-to-metal contact between the shroud and gripper-box discs that allow direct leakage of fields into the enclosed volume. The second peak, the diffusion current component (I_d), is primarily the result of the electric fields diffusing through the shroud material and is a function of the shroud material and its thickness. Table 6 summarizes the peak values of I_L and I_d for the shroud-clamp configurations tested.

Several conclusions can be made from comparing some of the results in Table 6. As expected, samples 1 and 2 show that the thicker 22-gauge material has a smaller diffusion signal (I_d) than the thinner 26-gauge material. Further, comparison of the banding techniques shows that the hose clamp allowed considerably higher leakage signals (I_L) than the

* Signode steel-banding stock, 0.015 by 1/2 in., distributed by Signode Corp.

** Signode Tensioner model P 3/8, 3/4 in. size, distributed by Signode Corp.

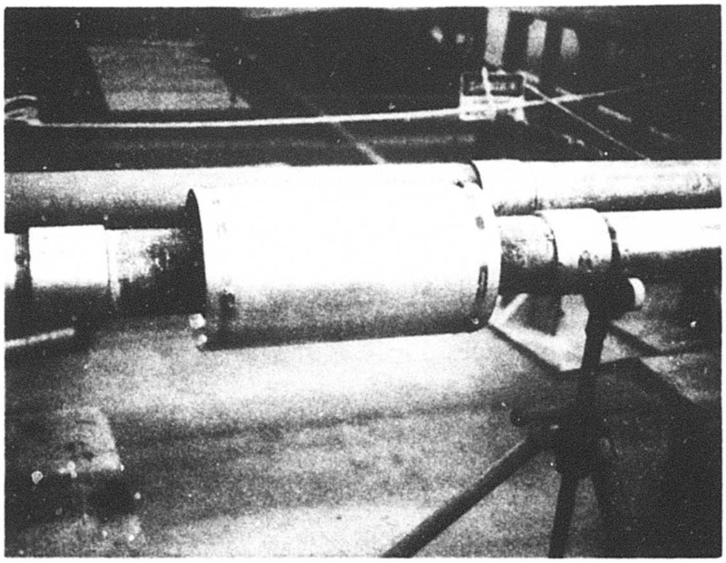

Figure 45. Cable-gripper box with shroud and stainless-steel hose clamps.

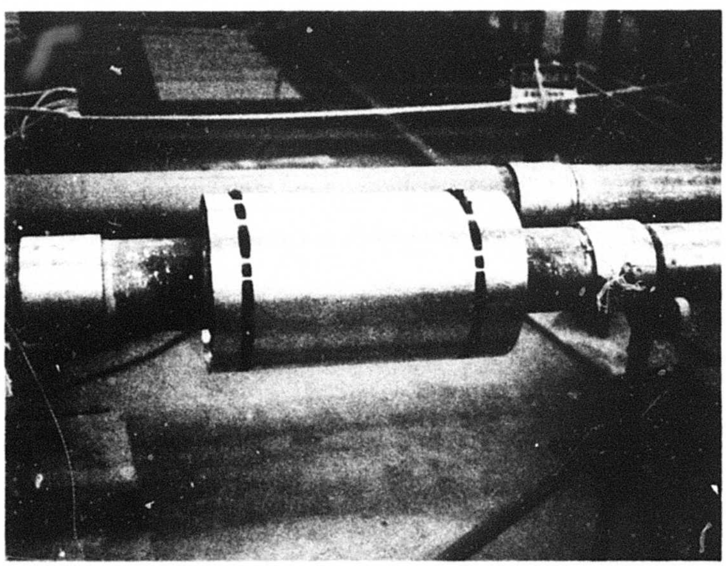

Figure 46. Cable-gripper box with shroud and metal shipping bands.

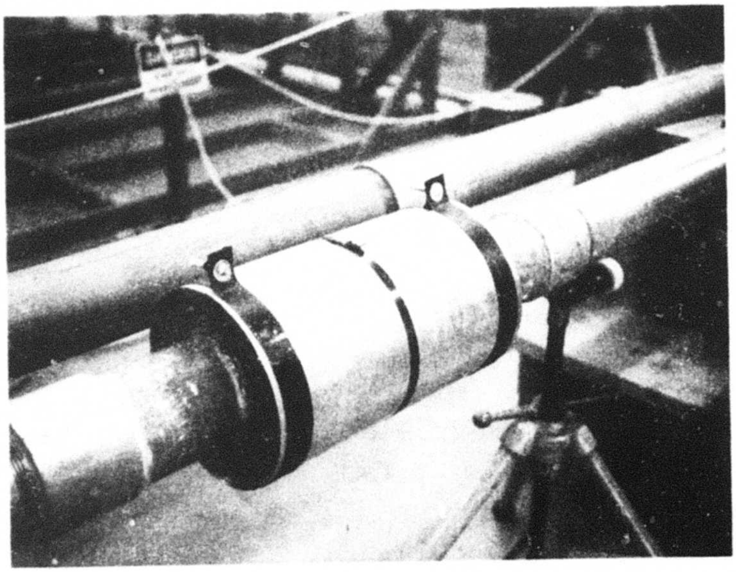

Figure 47. Cable-gripper box with shroud and locally manufactured clamps and one metal shipping band.

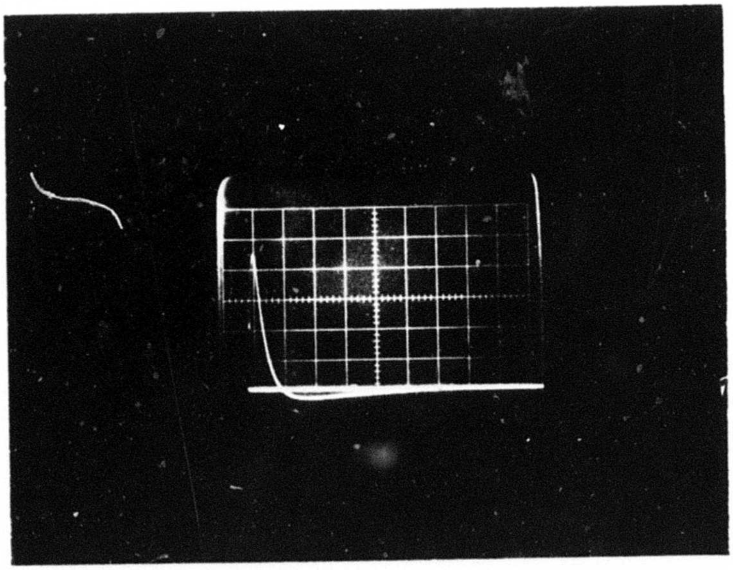

Figure 48. Single-layer shroud, 26 gauge (I_{sc}, 2 mA/div, 0.5 μsec/div).

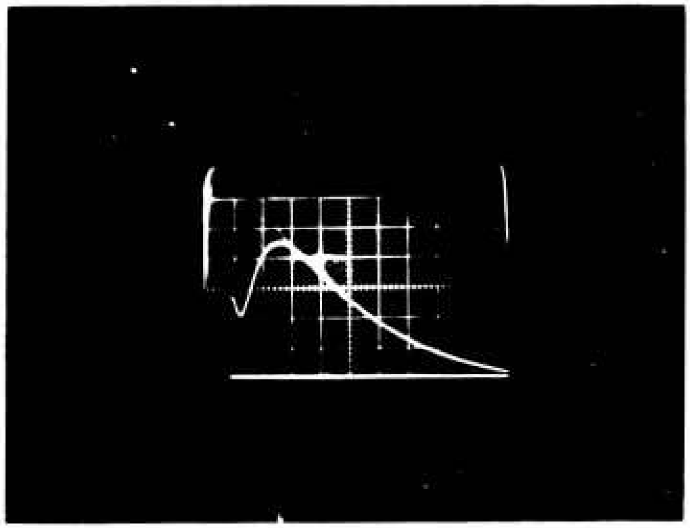

Figure 49. Single-layer shroud, 26 gauge (I_{sc}, 2 mA/div, 50 μsec/div).

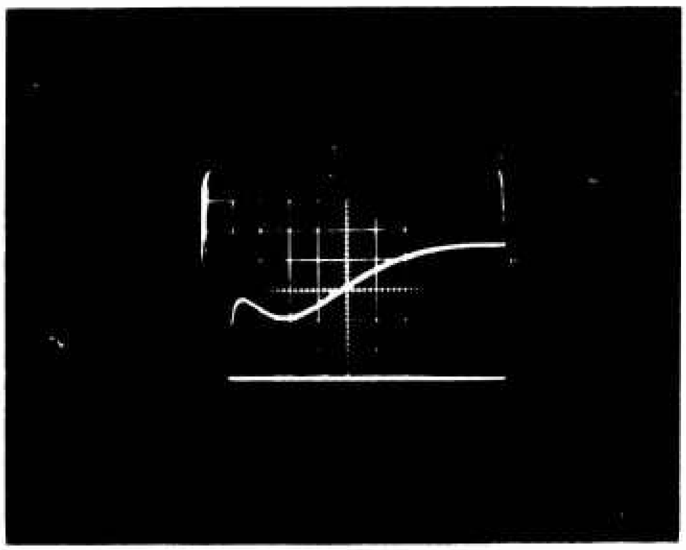

Figure 50. Single-layer shroud, 26 gauge (I_{sc}, 2 mA/div, 10 μsec/div).

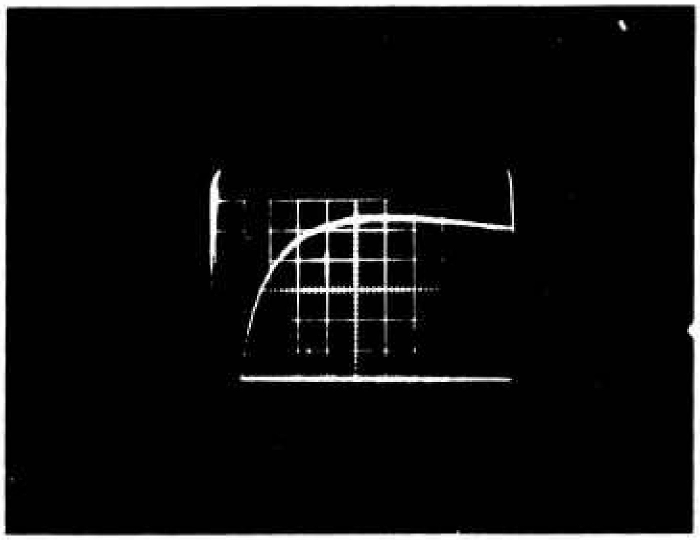

Figure 51. Single-layer shroud, 26 gauge (I_{sc}, 2 mA/div, 1 μsec/div).

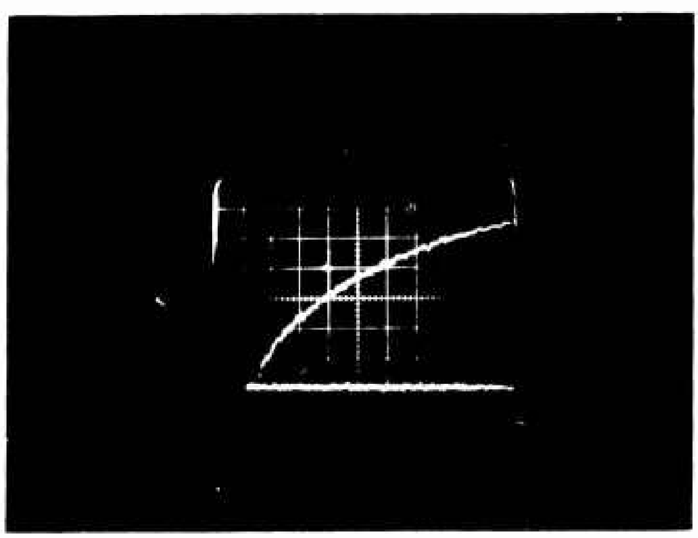

Figure 52. Single-layer shroud, 26 gauge (I_{sc}, 0.8 mA/div, 0.2 μsec/div).

Table 6

Test Data

Sample	I_L	τ_L*	I_d	τ_d**
1 layer, 22 ga. (CERL Band)	1.9 mA	2.2 μsec	3.1 mA	200 μsec
1 layer 26 ga. (hose clamps)	5.2 mA	2.4 μsec	8.8 mA	90 μsec
2 discont. layers 26 ga. (CERL Band)	1.14 mA	2.5 μsec	3.0 mA	180 μsec
2 discont. layers 26 ga. (Banding Machine)	3.05 mA	3.3 μsec	3.7 mA	340 μsec
3 discont. layers 26 ga. (Banding Machine)	9 mA	1.5 μsec	--	--
3 cont. layers 22 ga. (Banding Machine)	39 mA	1.5 μsec	--	--

*τ_L = rise time (0 to 90 percent of peak) for the leakage-current component (I_L) of I_{SC}.
**τ_d = time for diffusion current component (I_d) of I_{SC} to reach the peak value (where blank, no I_d component was measurable).

When the first pulse peak magnitude is large, the second peak is masked.

CERL band. This corresponds to previous results which indicated that sufficient pressure could not be obtained with the hose clamp to allow a good contact between the shroud and gripper box.

A direct comparison between the CERL bolt-on clamp and the shipping band can be made from the leakage currents of samples 3 and 4. As with the hose clamp, shipping bands do not provide sufficient pressure to insure a good shroud gripper-box contact. Comparing the diffusion signals from samples 3 and 4 with those from samples 1 and 2 indicates that two layers of the thinner 26-gauge metal are better than a single layer of 26-gauge metal, and are approximately equivalent to one layer of the thicker 22-gauge metal. This is expected since the 22-gauge metal is approximately twice as thick as the 26-gauge metal.

Comparison of samples 5 and 6 with sample 4 shows that increasing the number of shroud layers to more than two causes an increase in the leakage current. This is due to the difficulty in getting these multi-layer shrouds adequately tightened without buckling the shroud material. Comparison of samples 5 and 6 confirms that a continuous three-layer shroud would be harder to install than one made from three single layers.

In evaluating the effects of the 3/4-in. bolt penetration (Figure 53), the sense-wire, short-circuit current was first measured with the bolt removed. The bolt was then placed in the hole with flat washers under both the nut and the bolt head, and tests were repeated. In order to place the bolt in the hole, it was first necessary to remove the shroud and then reinstall it. Previous testing had shown that some variation in repeatibility of test data occurs with removal and reattachment of the shroud. The apparent effect of the open bolt hole, however, was a measurable increase of approximately 25 percent in the first-peak (leakage current) magnitude, but no change in the second-peak magnitude. Bolt-hole leakage with a tightened bolt in the hole is less than leakage from the shroud-to-disc interface and cannot be measured.

Conclusions and Recommendations. As stated earlier, an acceptable shroud covering for the cable-gripper boxes is a shielding equivalent to that of a wrench-tightened UNF union. This signal was found to have approximately a 10-mA peak for a 150-amp peak conduit current.[9] As shown in Table 6, samples 1 through 4 are acceptable from a shielding standpoint. However, due to the high diffusion signal from the 26-gauge single-layer shroud, the higher leakage due to the hose clamps, and the relative ease of installing one layer as opposed to two layers, it is recommended that a one-layer, 22-gauge galvanized sheet metal shroud be used on the gripper boxes, and that the shroud be held in place with a sturdy bolt-tightened clamp similar to the CERL clamp shown in Figure 47. The clamp used should provide pressure completely around the periphery of the shroud.

4 DEVELOPMENT AND EMP EVALUATION OF SHIELDS FOR NON-RFI TIGHT FLEXIBLE CONDUIT

Background. The conduit system at the SAFEGUARD site has been designed to form a continuous shield with the shielded volumes it interconnects. Conduit runs are terminated by welding them to the steel liner plates of the various structures. With this type of installation, some form of stress relief is required so that the differential-ground motion caused by a blast wave from a nuclear detonation will not break the conduit at the point where it enters the building. This stress relief is provided by the use of flexible conduit sections. There are basically two types of flexible conduits in use at the SAFEGUARD site: one type has been designed to be RFI-tight and another has not been designed to provide RFI shielding. Unfortunately, a number of the non-RFI tight flexible

[9] D. J. Leverenz, R. G. McCormack, and P. H. Nielsen, *Development and EMP Evaluation of Repairs for 4-In. Explosion-Proof Conduit Unions*, Letter Report E-45 (CERL, July 1973).

Figure 53. Cable-gripper box disc with 3/4-in. bolt installed.

conduit sections* have been installed in conduit runs in locations where exposure to EMP is likely. These conduits have been studied previously by CERL and were found to provide inadequate EMP shielding.[10] Thus, Huntsville Engineering Division has requested that CERL develop some method of increasing the EMP shielding effectiveness of these conduit sections. Because the wires had already been pulled through the conduits, any modifications had to be made without removing or replacing the conduits. Huntsville defined an acceptable modification as one that would lower the level of the signal induced on a wire passing through the modified conduit section to 40 or 50 dB less than the signal on a wire passing through an unmodified conduit section.

Approach. The Sealtite flexible conduit is constructed using a spiral-wrapping technique--with the wrapped edges being crimped together. Leakage-current levels are high due to the high contact resistance at the crimped edges. Diffusion current is also high due to the thinness of the wrap material. For this reason, shielding would be required that would provide adequate protection of the conduit section without destroying its shock-isolation properties.

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* Sealtite type EF metal hose, manufactured by Anaconda Metal Hose Division, Anaconda American Brass Company.

[10] D. J. Leverenz, R. G. McCormack, and P. H. Nielsen, *EMP Evaluations of Condu[illegible], Flex[illegible] [illegible], and Heated Conduit Couplings*, Letter Report E-11 (CERL, September 1972).

CERL has been successful in developing fixes for similar problems (Chapters 2 and 3), but in those cases, the external shields were made of 22- or 26-gauge galvanized steel, which would not provide the flexibility required for use with flexible conduits. The external-shield method was selected for testing. Test samples were fabricated using thin foils, wire meshes, and wire braids. The samples were tested using the injected current pulse techniques used by CERL in previous conduit evaluations.[11]

Experimental Procedure. Tests of the EMP shielding effectiveness of a 1-in. diameter, 18-in.-long, non-RFI tight flexible conduit section, with and without the various shielding modifications, were conducted by installing the flexible section between two sections of 1-in. rigid-wall, galvanized steel conduit. The rigid-wall conduit was cut so that the total assembly was approximately 10 ft long, with the flexible section at center. This assembly was then used as part of a parallel conduit transmission line. One end of the transmission line was terminated with a resistor equal to the characteristic impedance (Z_0) of the transmission line (approximately 200 ohms), and the other end was coupled to a pulse generator that injected a 3-ns rise time current pulse, with a 150-amp peak, into the transmission line.

The conduit assembly containing the flexible conduit test section constituted the ground side of the transmission line. It extended a few inches beyond the terminating resistor and was coupled to a conduit stub that had been welded to a panel in the side of a shielded room. A #12 copper wire, referred to as the sense wire, was connected to the end cap of the conduit containing the test sample and extended through the inside of this conduit, passing through the test section and into the shielded room where the wire was grounded to the chamber wall. An oscilloscope and Tektronix P6021 current probe, with a combined bandwidth of 10 Hz to 36 MHz,* were used inside the shielded room to measure the current induced in the sense wire (I_{SC}) by the current pulse that was injected into the transmission line. The magnitude of I_{SC} is directly related to the shielding effectiveness of the conduit assembly through which the sense wire passes. Prior tests[12] have shown that a continuous (i.e., no joints) rigid-steel conduit and an assembly consisting of conduit sections that have been properly joined (i.e., clean threads that have been coated with Chomerics #4331 conductive compound and then tightened to approximately 200 ft-lb of torque for 1-in. diameter conduit)

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[11] D. J. Leverenz, R. G. McCormack, and P. H. Nielsen, *The Effect of Conduit Coupling Conditions on the EMP Shielding of Conduit Joints*, Letter Report E-4 (CERL, July 1972).

[12] D. J. Leverenz, R. G. McCormack, and P. H. Nielsen, *The Effect of Conduit Coupling Conditions on the EMP Shielding of Conduit Joints*, Letter Report E-4 (CERL, July 1972).

* Tektronix P6021 current probe and either a Tektronix 454A or 7623 oscilloscope.

provide sufficient EMP shielding to reduce the signal induced on a sense wire to a level that is too small to measure with the instrumentation used (> 50 μamp). Thus, since all the joints in the conduit assembly containing the test sample were properly joined, any signal induced onto the sense wire was a result of shielding degradation caused by the flexible conduit section being tested.

Figures 54 and 55 show the parallel conduit transmission-line test arrangement. This test setup is nearly identical to those described earlier in this report.

<u>Test Samples</u>. The 1-in. diameter, 18-in.-long Sealtite flexible conduit section was tested as manufactured and with several types of external shields added in an effort to determine a method of significantly improving the shielding effectiveness of this type of flexible conduit. The shielding methods tested are described below. The same flexible conduit sample was used throughout the tests to maintain a common reference for all data.

The flexible conduit was first tested as manufactured (test sample 1, Figure 56) and then with a 6-gauge copper wire (ground strap) in parallel with the flexible section (test sample 2, Figure 57). The wire was securely held in place by binding posts on each end fitting. The posts had been included by the manufacturer for this purpose.

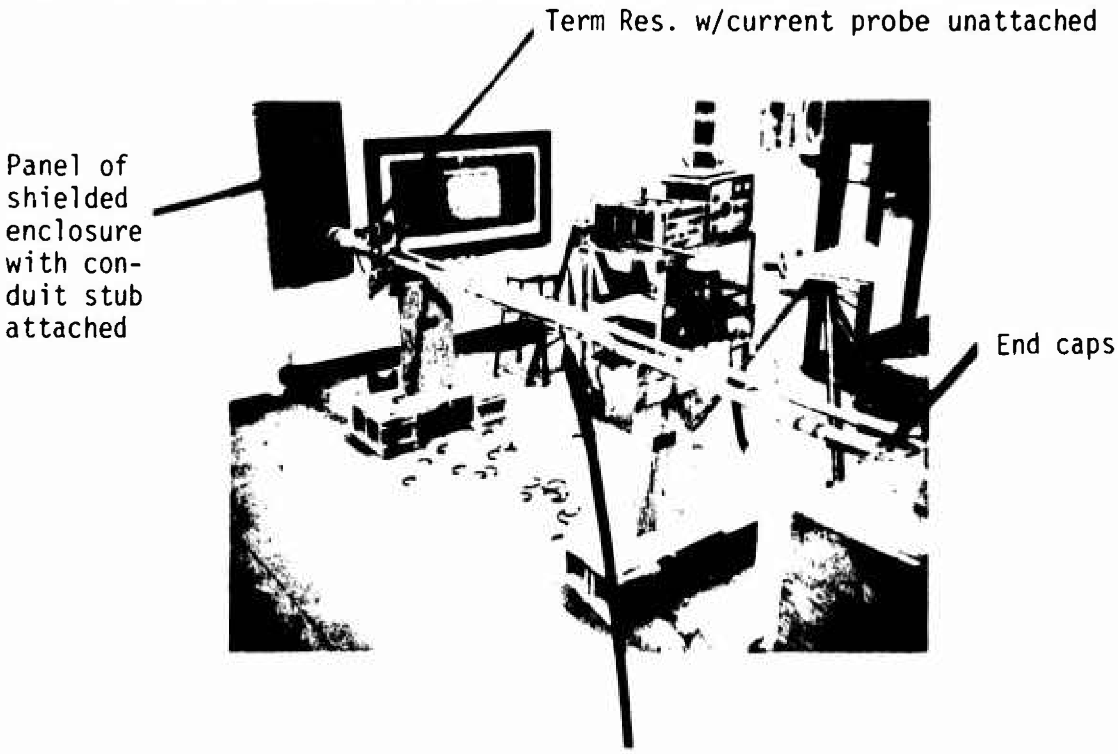
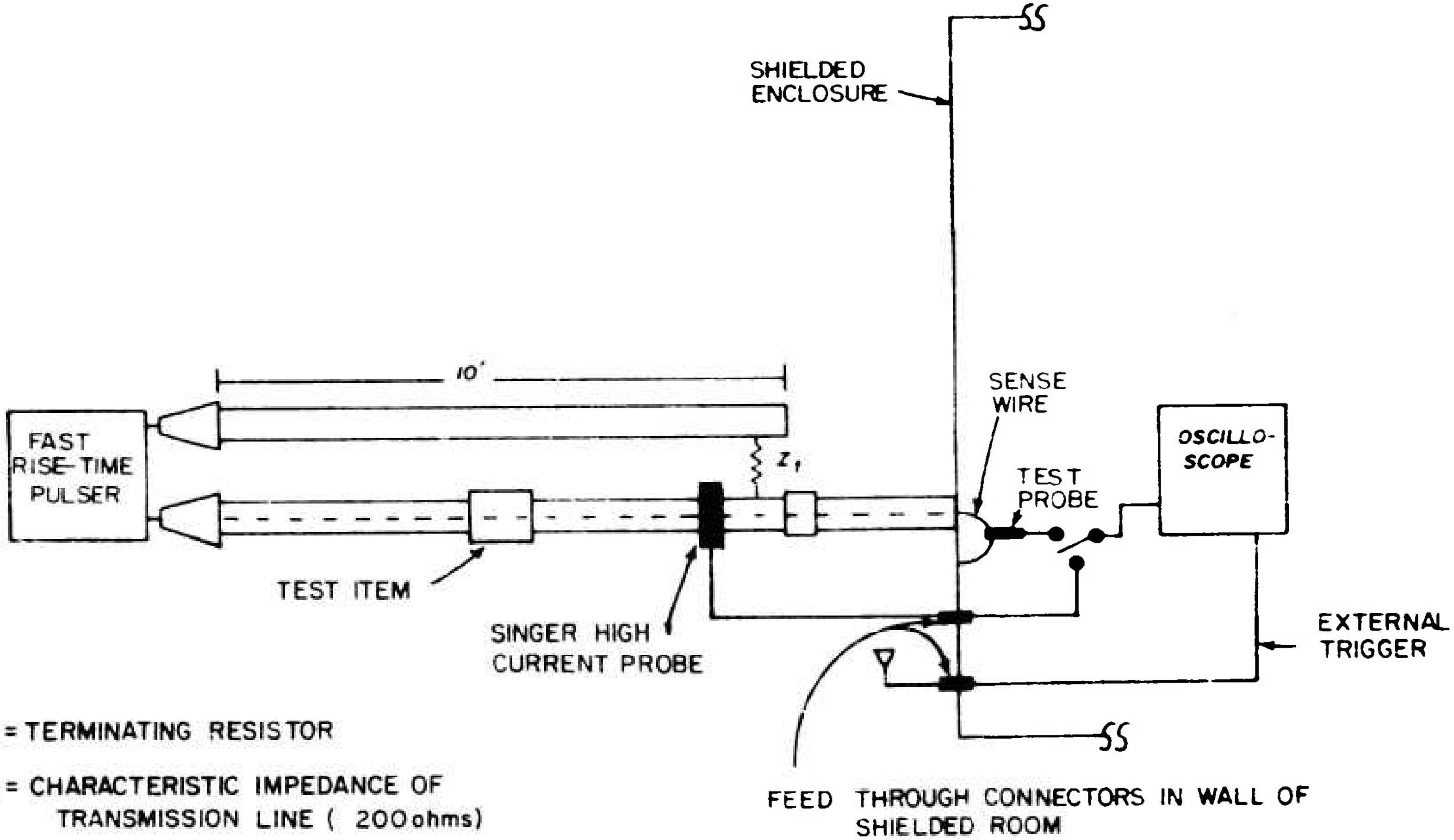


Figure 54. Parallel conduit transmission-line test assembly.



Z_t = TERMINATING RESISTOR

Z_o = CHARACTERISTIC IMPEDANCE OF TRANSMISSION LINE (200 ohms)

$Z_t = Z_o$

Figure 55. Block diagram of parallel conduit transmittion-line test setup.

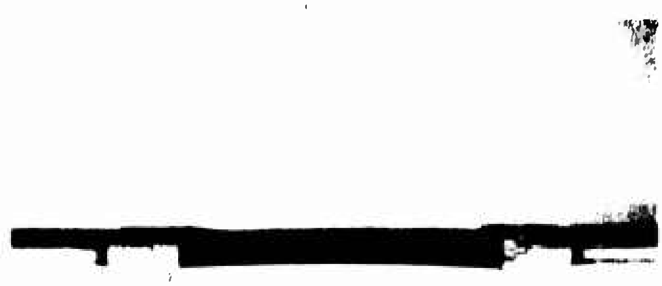


Figure 56. Non-RFI tight flexible conduit test sa ple (test sample 1).

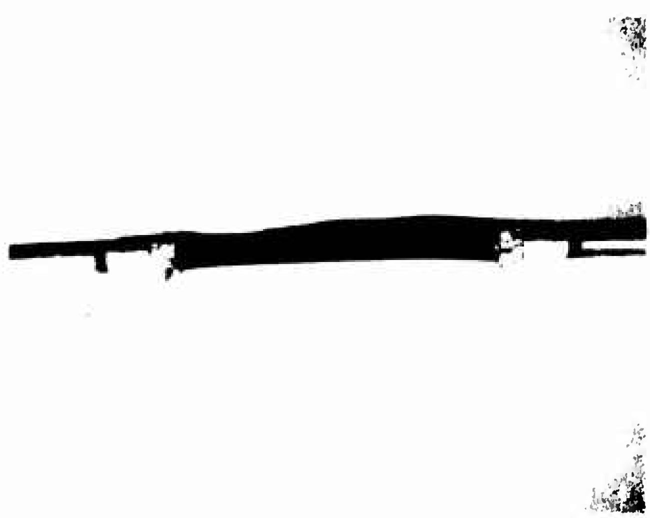


Figure 57. Non-RFI tight flexible conduit test sample with 6-gauge copper wire ground strap (test sample 2).

Test sample 3 consisted of enclosing the flexible conduit with a 2-ft long section of size #2 ZIP-EX-2 EMI cable shielding* installed over the entire flexible conduit section and secured by nylon-reinforced tape (Figure 58).**

Test sample 4 was made by wrapping the flexible section with Monel wire mesh+ so that approximately eight layers of mesh covered any given portion of the Sealtite section plus couplings. Four automotive screw type, stainless-steel hose clamps were used to secure each end of the wrapping to the conduit assembly (Figure 59).

After data were taken on the assembly as described above, the Monel wire mesh wrapping was tightly wrapped (test sample 5) with nylon-reinforced tape to reduce the contact resistance between the mesh wrapping and the conduit assembly (Figure 60). The hose clamps were not disturbed when the tape was applied.

Further tests of this same assembly were conducted using strips of 1/8 in. thick by 3/4 in. wide tinned copper braid in parallel with the flexible conduit section that was wrapped with the Monel mesh and nylon-reinforced tape. Data were taken using one, two, and three strips of the tinned copper braid (test samples 6, 7, and 8, Figure 61). In all cases, the strips of tinned copper braid were securely clamped to the conduit assembly using two automotive screw type, stainless-steel hose clamps. The wrapping was not disturbed in any way.

Tests were also conducted on the flexible conduit assembly with a galvanized steel braid++ installed over it (test sample 9). This braid was a sleeve that was modified for ease of installation under field conditions. This modification consisted of applying a narrow strip of solder along the length of the sleeve so that it could be cut without unraveling along the cut edge. The resulting split-sleeve braid was installed on the conduit using tightly installed steel shipping bands# and automotive screw type, stainless-steel hose clamps (Figure 62).

Additional tests were conducted using a similar galvanized steel braid sleeve that had not been modified (test sample 10). This sleeve was installed over the flexible conduit section by sliding it intact

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* Cable shielding distributed by Metex Corporation, Edison, NY.

** Scotch filament tape manufactured by Minnesota Mining and Mfg. Co., St. Paul, MN.

\+ Monel mesh material, in a strip 5 in. wide and 5 ft long, wire diameter 0.0045 in., distributed by Metex Corporation.

++ Same galvanized braid used on Anaconda RFI-tight flexible conduit, diameter size 0.026 in.

\# Signode steel banding stock, 0.015 x 1/2 in., tightened as much as possible without breaking by using Signode Tensioner banding machine, model P3/8, size 3/4, both distributed by Signode Corp.

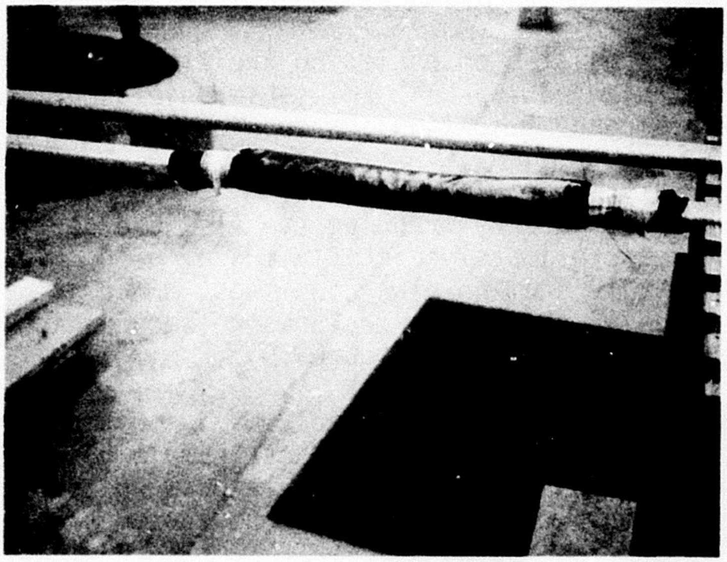

Figure 58. Test sample with conduit section covered with ZIP-EX-2 cable shielding (test sample 3).

Figure 59. Test sample with conduit section wrapped with Monel wire mesh (test sample 4).

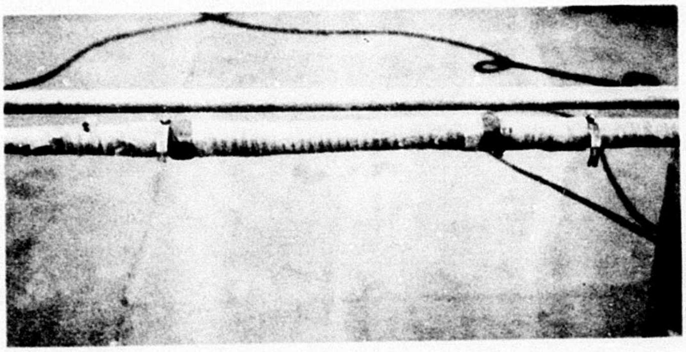

Figure 60. Test sample with conduit section wrapped with Monel wire mesh and then wrapped with nylon-reinforced tape (test sample 5).

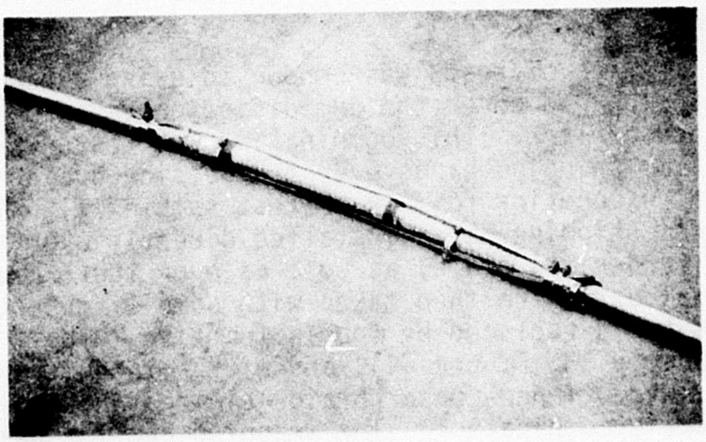

Figure 61. Test sample with conduit section wrapped with Monel wire mesh and nylon-reinforced tape over which three tinned copper braid straps have been clamped (test sample 8).

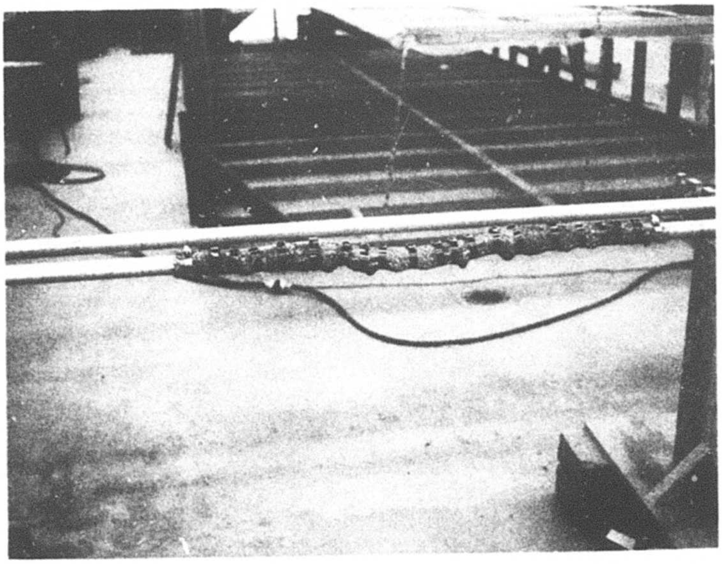

Figure 62. Test sample with conduit section covered by split galvanized steel braid sleeve (test sample 9).

over the end of the conduit assembly. It was tightly secured to the test assembly using steel shipping bands (Figure 63). Data were compared with data obtained using the split-sleeve braid to determine if the sleeve modification had significantly degraded the shielding effectiveness of the steel braid.

The final series of tests was conducted using a high-permeability, metal-foil wrapping* to cover the unmodified galvanized steel braid sleeve described earlier. This combination was tested first using tightly installed shipping bands over the outside braid to secure both the braid and the Conetics foil wrap (test sample 11). Data were also taken with steel shipping bands installed directly over the Conetics foil wrapping (under the braid) as well as over the braid (test sample 12). Additional data were then taken with some of the steel shipping bands over the braid replaced by four automotive, U-bolt type muffler clamps (test sample 13, Figure 64), and with a long strip of 1/8 in. thick by 2 in. wide tinned copper braid clamped in parallel with the wrapping and braid combination. The wrapping and the braid were each clamped independently with steel shipping bands (test sample 14).

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* Conetics foil, 0.006 in. thick, relative permeability of 225,000, 78 percent nickel, 1 1/2 percent chrome, 4 1/2 percent copper, 16 percent iron, dry H_2 annealed, volume resistivity of 60 by 10^{-6} ohms-cm, manufactured by Perfection Mica Co.

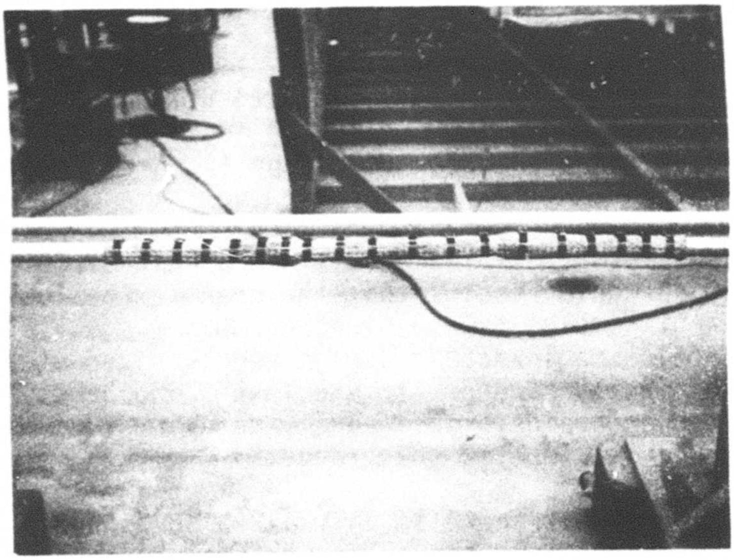

Figure 63. Test sample with conduit section covered by galvanized steel braid sleeve--not split (test sample 10).

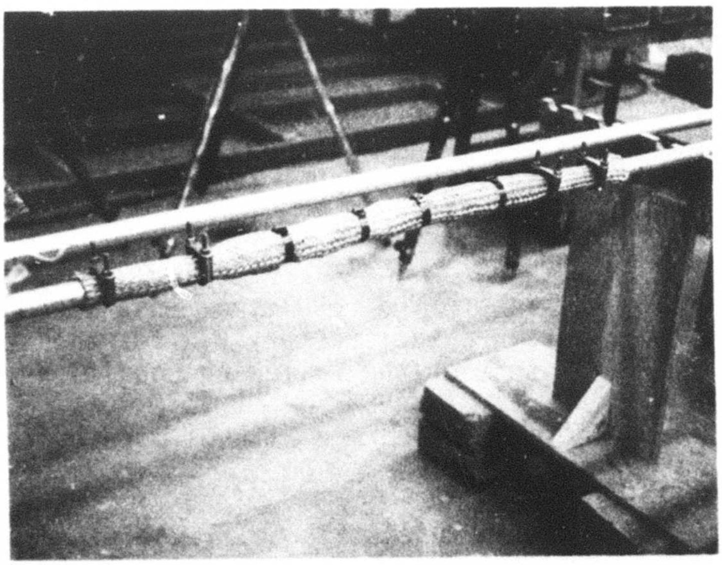

Figure 64. Test sample with conduit section covered by Conetics foil and a galvanized steel braid sleeve (not split) held in place with steel shipping bands and muffler clamps (test sample 13).

Test Results. Figures 65-71 show typical I_{sc} wave forms for some of the shielding modifications tested. These pictures were chosen as representative of the type of data obtained during the test. Test results are summarized in Table 7 where the peak values of I_{sc} are listed for each test sample.

Since the unshielded flexible conduit had a peak of 6000 mA, a shielding of 40-50 dB would require that the peak I_{sc} be lowered to 20-60 mA. Some of the test samples (10-13) reached this range, but only the combination of Conetics foil wrapping, plus a galvanized steel braid (each of which are tightly banded with steel shipping bands), plus a very long tinned copper braid (also securely held in place with steel shipping bands) reduced I_{sc} below this range.

It should be noted that there is only a 2-3 dB difference between the signal level measured using the split-braid sleeve and the signal level using the braid sleeve that is not split. It is not unreasonable, however, to expect a variation of approximately 2 dB in signal levels measured using different test samples of the same type. A fair conclusion is that a split galvanized steel braid sleeve will provide shielding equivalent to that of a similar sleeve that is not split.

In addition to the variation in peak values of I_{sc} shown in Table 7, there is a considerable variation in the rise times of I_{sc} (Figures 65 to 70). This variation in rise time is due to differences in the shielding properties and thicknesses of the various materials used in making the shields. The exact explanation is complex because I_{sc} is a combination of signals leaking through the external shield and diffusing through the external and flexible conduit. This combination can be seen in the double-peaked trace of Figures 69 and 70. It should be noted that the undershoot shown in Figure 68 is due to the limited low-frequency response of the measuring equipment and not to a reverse in the diffusion signal.

Conclusions and Recommendations. The results of this study indicate that it is difficult to obtain a satisfactory fix for the Sealtite flexible conduit. A fix must meet the following conditions:

a. Installation is to be performed without opening the conduit, since wires have already been pulled.

b. The resultant section must still be flexible.

c. The shielding improvement is to be 50 dB or greater.

The only test sample that met these requirements was the one that consisted of a layer of Conetics foil covered with a galvanized steel braid sleeve and parallel copper braids (Figure 64). Each layer of material was securely clamped in place with steel shipping bands.

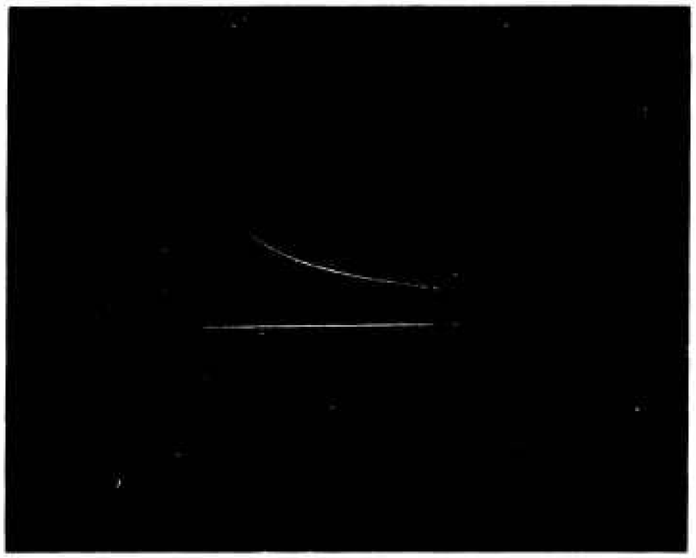

Figure 65. I_{SC} wave form--flexible conduit section without any additional shielding, test sample 1 ($I = 2$ A/div, $\tau = 5$ μsec/div).

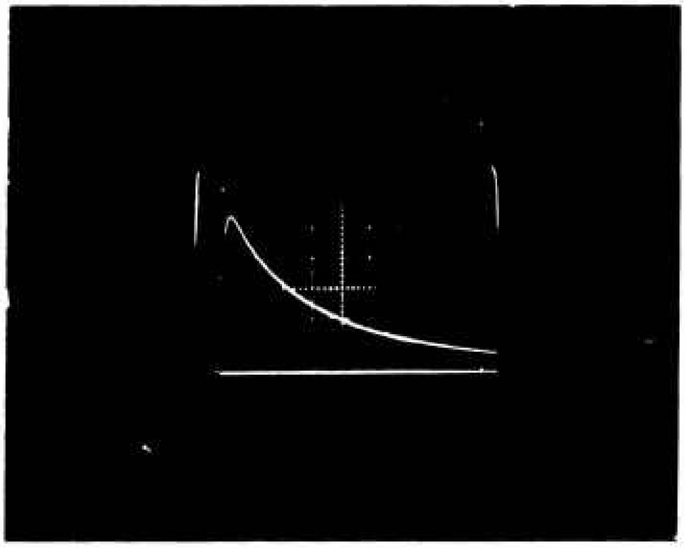

Figure 66. I_{SC} wave form--flexible conduit section wrapped with Monel wire mesh held with hose clamps and tape, test sample 8 ($i = 500$ mA/div; $t = 20$ μsec/div).

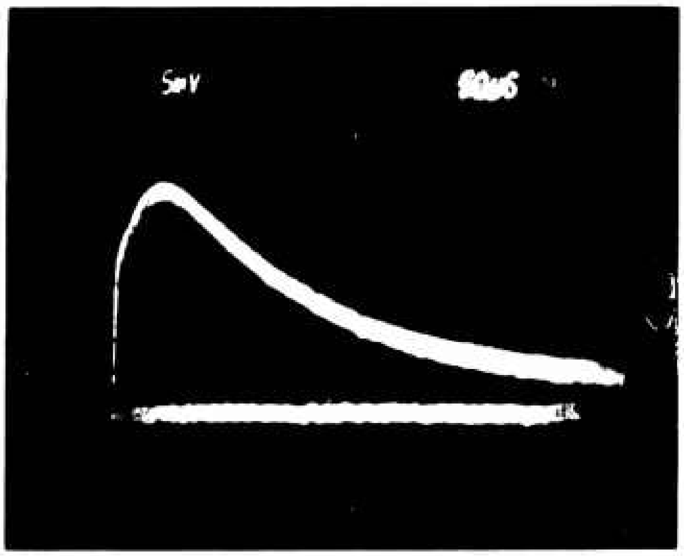

Figure 67. I_{sc} wave form--flexible conduit section covered with split galvanized steel braid sleeve, test sample 9 (i = 20 mA/div; t = 50 μsec/div).

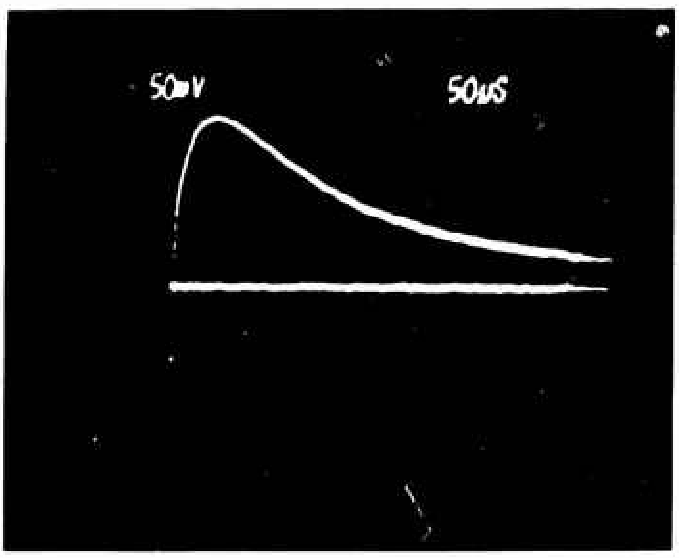

Figure 68. I_{sc} waveform--flexible conduit section covered with galvanized steel braid sleeve (not split), test sample 10 (i = 20 mA/div; t = 50 μsec/div).

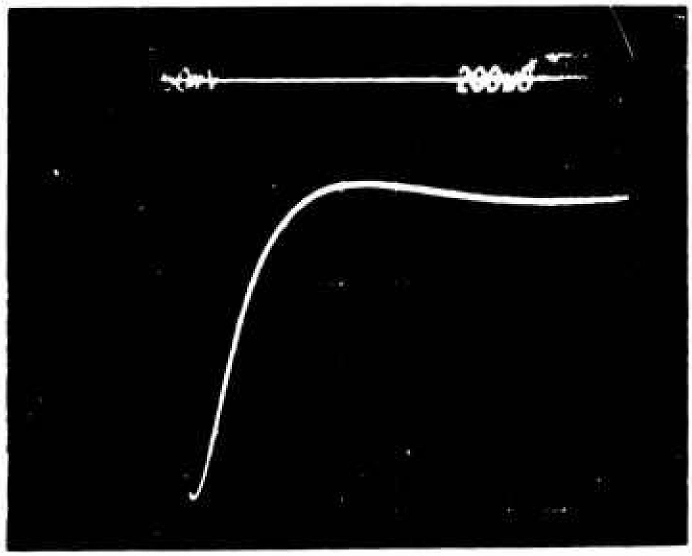

Figure 69. I_{sc} wave form--flexible conduit section wrapped with Conetics foil and braid sleeve, with bands on sleeve only, test sample 11 (i = 5 mA/div; t = 200 μsec/div).

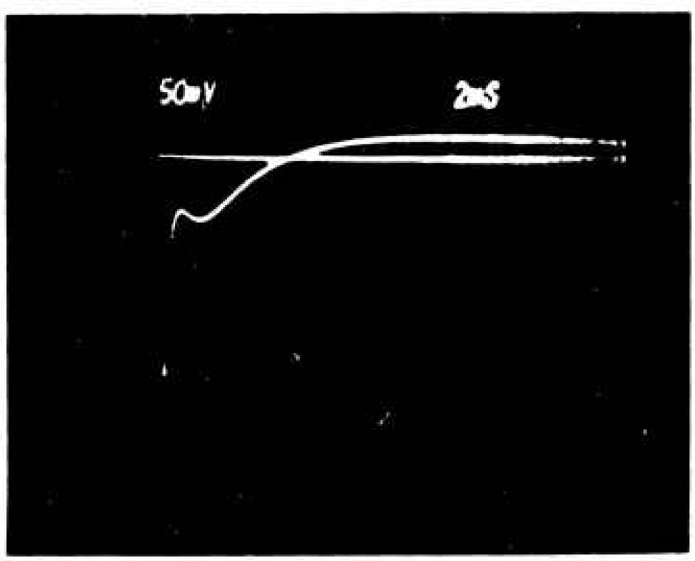

Figure 70. I_{sc} wave form--flexible conduit section wrapped with Conetics foil and braid sleeve, with bands on sleeve only, test sample 11 (i = 10 mA/div; t = 2 μsec/div).

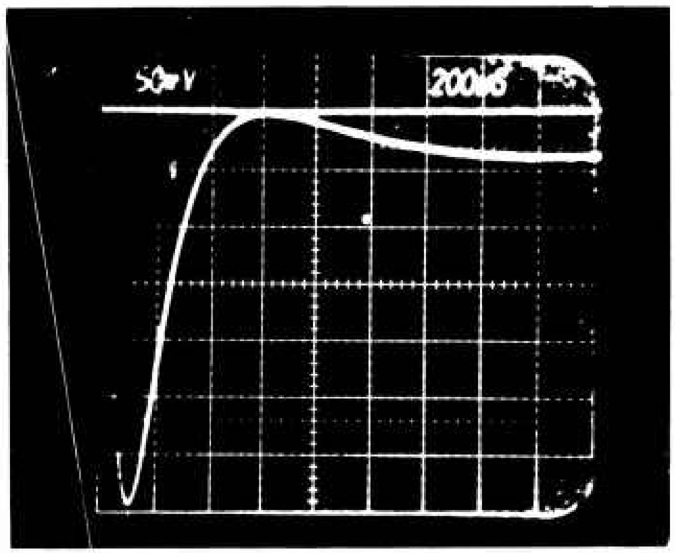

Figure 71. I_{SC} wave form--flexible conduit section with Conetics foil and braid sleeve (bands on both), tinned copper braid strap in parallel, test sample 14 (i = 2 mA/div; t = 200 μsec/div).

Table 7

Summary of Peak Values of I_{sc} for Sealtite Conduit Test

Sample No.	Description	I_{sc}* (mA)
1	Flexible-conduit reference	6,000-7,000**
2	Conduit + 6-gauge wire	2,900
3	Conduit + ZIP-EX-2	1,550
4	Conduit + Monel mesh + hose clamps	3,400
5	Test sample 4 plus tape	2,600
6	Test sample 5 with one parallel braid strap	1,500
7	Test sample 5 with two parallel braid straps	960
8	Test sample 5 with three parallel braid straps	460
9	Conduit + split galvanized braid sleeve + bands + hose clamps	77
10	Conduit + galvanized braid sleeve + bands	60
11	Conduit + Conetics wrap + galvanized braid sleeve + bands on braid	37
12	Conduit + Conetics wrap + galvanized braid sleeve + bands on Conetics and braid	38
13	Test sample 12 with radiator clamps	38
14	Test sample 13 with braid strap	14

* I_{sc} is the peak value of the short-circuit current measured on the sense wire.

** Two test samples were tested in a similar configuration.

It is therefore recommended that a fix similar to test sample 13, except using the split galvanized steel braid, be used to repair non-RFI tight flexible conduits that are expected to be in an EMP environment. This fix can provide the required shielding and be installed without removing the flexible conduits.

5 CONCLUSIONS

EMP energy leaks into conduit systems when the EMP induced current on the conduits flows over conduit assemblies that have defects, such as broken or cracked hardware, improperly assembled threaded couplings, or hardware items not designed for EMP protection. The best way to correct these leaks is to repair or replace the faulty condition in the conduit run. Unfortunately, there are times when the faulty assembly cannot be corrected or sufficiently altered to provide the required EMP shielding. When this occurs, some other method of external repair must be used.

The external fix, instead of repairing the faulty condition, provides alternate paths for the induced conduit current and thus minimizes the current that flows over the faulty assembly. In addition, the fix must also shield the faulty conduit assembly from the fields produced by the induced conduit currents. Based on the results of this investigation, CERL has formulated some general guidelines for developing this type of fix.

Even in conduit runs that are improperly assembled, providing alternate paths for the conduit current is not a simple task since the impedance of the path along the conduit is extremely low compared to most simple jumper paths. Alternate paths made by using jumper wires alone provide little reduction in the current flowing on the conduit. Even multiple copper jumper wires made of wide braid were ineffective. The problem is twofold. First, the conduit current, with its 10-ns rise time, has high-frequency energy that makes the inductive reactance of the jumper wires high compared to the resistance of the path down the conduit. Secondly, even if most of the current could be induced to flow on the jumper cables, this would not be an acceptable fix since the defective conduit assembly is not shielded from the fields produced by the current on the jumper wires.

If, instead of the jumper wires, a shroud is used that completely covers the defective conduit assembly (essentially placing the faulty conduit section inside a second conduit), then an alternate low-impedance path can be provided for the conduit current, thus providing a shield for the defective conduit. The low impedance of the shroud is partially due to the effect that induces high-frequency currents to flow on the outer surface of conductors. To make the shroud effective, however, the contact resistance between it and the conduit must be very low. If this is accomplished, the currents flowing on the conduit will transfer to the shroud and bypass the faulty conduit assembly.

To produce the necessary low-contact resistance, the mating surfaces between the shroud and conduit must be clean and a clamping arrangement must be used that provides a uniform pressure around the entire circumference of the conduit and shroud. CERL found that automotive muffler type clamps, radiator hose type clamps, or a similar type of clamp were most satisfactory for this application. Often, multiple clamps provided increased shielding.

The shroud should be of good shielding material, such as galvanized steel or some form of high-permeability metal such as Conetics foil. The thickness of the material used in the shroud is very important. If it is too thin it will not provide adequate shielding and diffusion signals will easily penetrate and induce currents on the conduit. If the material is too thick, the shroud cannot be easily formed and it is difficult or impossible to clamp it to the pipe to get a sufficiently low contact resistance. CERL has found that 22- to 26-gauge materials work best--depending on the type and number of layers of material.

The shroud can be made from several layers of the same or different thin materials or from one layer of a thicker material. CERL has found that more than two layers is usually not satisfactory since it becomes increasingly difficult to clamp the layers to the conduit without buckling and thus lowering contact resistance. It was also found that longitudinal seams, defects, or overlaps have little effect on shielding effectiveness. Therefore, the seams in the shroud that run in the same direction as the conduit need not be sealed. A shroud wrapped around the conduit works as effectively as a shroud with its seams welded.

It is CERL's recommendation that a preformed shroud, such as the Bishop type described in Chapter 2, be used when defects are found in rigid runs of conduit. Bishop shrouds provide good shielding, are easy to fabricate, and their installation requires little or no training. When a fix has to be made in a flexible conduit run, a repair similar to that described in Chapter 4 should be used. This type of fix will provide a flexible shroud, but the shielding is not as effective as with the preformed shrouds. The shroud must be carefully installed to insure a good shroud-to-conduit contact. All of the guidelines described herein should aid in the formation of a fix that will provide adequate EMP shielding.

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